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An Analysis of Fires in Passenger Cars, Light Trucks, and Vans

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16. Abstract

This report contains an analysis of historical data on fire occurrence in fatal and less serious crashes as a function of crash, vehicle, and driver characteristics that influence the likelihood of postcollision vehicle fires.

The report is organized into four sections. Data on the vehicles included in the study are for 1978 and later model years. The first two sections use 1979 thru 1992 data from the Fatal Accident Reporting System (FARS). The first section contains raw cross tabulations of the data. The second section constructs multivariate statistical models. Section three examines raw cross tabulations of data from the State of Michigan from 1982 to 1991. The Michigan police accident report (PAR) collects data on fuel leaks which are used to estimate the relationship between fires and fuel leaks. Section four is based on the National Accident Sampling System Crashworthiness Data System (NASS CDS) for burn injuries from 1988 to 1993.

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Introduction

The objective of this study was to analyze fire occurrence in fatal and less serious crashes, as a function of crash, vehicle and driver characteristics levels that influence the likelihood of postcollision vehicle fires. This analysis provides information to address potential changes to Federal Motor Vehicle Safety Standard 301, Fuel System Integrity, to increase the effectiveness of that standard in preventing postcollision vehicle fires.

The current Standard 301 became effective in 1978 and applied to passenger cars, light trucks and vans. To prevent vehicles not meeting this standard from corrupting the data, all vehicles analyzed in this report have a model year of 1978 or later. As a result of this restriction, the data does not include all crashes, in which a fire occurred. This study consists of four sections, which complement each other. The first two sections use data from the Fatal Accident Reporting System (FARS). FARS consists of a census of all fatal crashes and is therefore not a representative sample and contains crashes that are of the highest severity. The first section contains raw cross tabulations of data for 1978 and later model year vehicles. This section of univariate and bivariate analysis, examines the effects of the data variables one or two at a time. The second section of the study also uses the FARS data to construct multivariate statistical models which simultaneously adjust for the effects of the included variables. Section three examines raw cross tabulations of data from the State of Michigan. The Michigan police accident report (PAR) collects data on fuel leaks, which are used to estimate the relationship between fires and fuel leaks. The Michigan data from 1982 to 1991 were used in this study. Section four is based on the National Accident Sampling System Crashworthiness Data System (NASS CDS) for burn injuries from 1988 to 1993.

In 1979, FARS added a new field, the Most Harmful Event. The FARS data analysis, including the Most Harmful Event field, from 1979 through 1992 are included in this report. The vehicles covered by Standard 301, passenger cars, light trucks, and vans, are analyzed separately in sections 1, 2 and 3. The NASS analysis of section 4 partitions the vehicle types into two categories: cars and light trucks and vans.

Definition of FARS Fire Occurrence and Most Harmful Event Fire

The Fatal Accident Reporting System has two levels of fire occurrence, recorded at the vehicle level, which were considered in the first two sections of this analysis: the occurrence of a fire, and the determination that the fire was the most harmful event (MHE). The occurrence of a fire is an objective measure based on information provided in the police accident report; i.e., a fire either occurred and was noted or it did/was not. The determination that a fire was the most harmful event requires the personal judgment of the FARS data analysts in each state. This determination sometimes is based on the availability of a death certificate that includes N-codes (nature of injury) describing the injuries contributing to the person's death. However, most of the time this is not the case, and the determination is based on information provided in the narrative of the police accident report. The most harmful event field is of special importance when the first harmful event is minor, for a particular vehicle, compared to some subsequent event. When coding the most harmful event, fatalities take precedence over injuries, which take precedence over property damage. If a vehicle is involved in more than one event that causes a fatality to its own occupants or to nonmotorists, the event which causes the greatest number of fatalities to occupants of the vehicle is chosen. If the number of fatalities for two or more events are equal, then the

event that caused the most serious injury or property damage is selected as the most harmful event. If the vehicle is not involved in an event that causes a fatality to its occupants or to a non-motorist then the event which produced the worst injury is chosen as the most harmful event. If a vehicle is not involved in an event that causes either a fatality or an injury to its occupants, then the event causing the most property damage is chosen as the most harmful event. If in doubt of what is the most serious event, the event that occurred first in time will be identified as the most harmful event. The fact that fire was identified as the most harmful event does not necessarily mean that there was a fatality in the particular vehicle due to fire. Also, if a vehicle fire was not classified as the most harmful event, then this does not mean that no death was caused by fire.

Based on the most harmful event code and some simplifying assumptions of the FARS data, accepted conventional practices estimates that 2700 and possibly as many as 4973 individuals have died as a result of a fire in a 1978 model year or later car, light truck, or van since 1979.

Data

The data were partitioned by several variables:

Vehicle type:

> Cars: Passenger cars of model year 1978 and later.
>
> Light trucks: Trucks with a gross vehicle weight rating (GVWR) of not more than 10,000 pounds of model year 1978 and later. The National Highway Traffic Safety Administration (NHTSA) includes utility vehicles in this category.
>
> Vans: Passenger vans and cargo vans of model year 1978 and later.
>
> LTV: Light trucks and vans of model year 1978 and later.

Year of crash: The calendar year in which the crash occurred.

Model year: The model year for the vehicle under analysis. Model years typically begin in the fall of the preceding calendar year and continue generally through the end of the calendar year.

Vehicle age: The age of the vehicle in years as defined by calendar year minus model year, if the model year was less than the calendar year, otherwise the vehicle age is set to zero.

Number of vehicles involved in a crash: This was defined as a dichotomous variable, i.e., two levels, either one vehicle or more than one vehicle involved.

Age of driver: The age of the driver, of the vehicle under analysis, in years.

Area of damage: The principal impact point of damage to the vehicle under analysis. The data were partitioned into five categories.

Rollover: The vehicle rolled at least one quarter of a full turn.

Front: The vehicle does not rollover and has principal damage to the front of the vehicle, i.e., clock positions 11, 12, or 1.

Rear: The vehicle does not rollover and has principal damage to the rear of the vehicle, i.e., clock positions 5, 6 or 7.

Side: The vehicle does not rollover and has principal damage to the side of the vehicle, i.e., clock positions 2, 3, 4, 8, 9, or 10.

Other: The vehicle does not rollover and has principal damage to an area other than the front, rear, or side, for example, the undercarriage or roof.

Rollover: The vehicle rolled at least one quarter of a full turn. The difference between this variable and the preceding variable is that the front, rear, side and other were collapsed into the single response of nonrollover.

Weight: This variable applies only to cars. The curb weight of the vehicle measured in pounds.

Salt effect: This variable partitions the states into the "salt belt" states that use salt and other corrosive material on roadways which affect vehicle corrosion, the "sun belt" states and other states. The states of Connecticut, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin are considered the "salt belt" states. The "sun belt" states are defined to be Alabama, Arizona, Florida, Georgia, Hawaii, Louisiana, Mississippi, New Mexico, South Carolina, and Texas. All other states and the District of Columbia are considered other states.

Speed limit: The posted speed limit in mph.

Object struck: The kinematics of a crash are dependent on the type of object struck by the vehicle under analysis. The objects were partitioned into five mutually exclusive sets using the FARS definitions of first harmful event. Note that object struck is the first object struck or an overturn, if that occurred first.

Vehicle: If the vehicle struck a motor vehicle of any kind.

Narrow: A narrow stationary. Narrow objects include: highway/traffic sign posts, overhead sign supports, luminary/light supports, utility poles, fire hydrants and trees.

Fixed: Large blunt objects. Fixed objects include: boulders, buildings, impact attenuators/crash cushions, bridge piers or abutments, bridge parapet ends, guardrails, concrete traffic barriers, longitudinal barriers, culverts, curbs, ditches, embankments, fences, and walls.

Overturn: Initial impact is not striking an object, but is caused by the overturn of the vehicle under analysis.

Other: Records that do not fall into one of the other categories.

Extrication: Extrication refers to the use of equipment or other force to remove one or more persons from a vehicle, i.e. more than just lifting or carrying an individual out of the wreckage.

Leak: A fuel leak associated with the crash - Michigan data only.

Injury: An incapacitation injury, non-incapacitating injury or possible injury - Michigan data only.

Burn Injury: An individual who was coded as having a burn injury caused by a vehicle fire - NASS data only.

Analytic Note

This report makes extensive use of univariate and bivariate tables. Although these tables may provide useful insight to the causes and outcomes associated with vehicle fires the possibility exists that the results may be confounded with one or more lurking variables. This is a limitation of this form of analysis which is often overlooked.

The univariate and bivariate tables, from census data, either provide point estimates or estimates of trends. When point estimates are the purpose of the table, the 95 percent confidence limits are included. If trends are desired, a graph that illustrates the trend or lack of a trend is included.

A crash must occur for data to be include in the FARS, Michigan and NASS data sets, therefore the data is never an estimate of the behavior of the entire population. The FARS data set has a higher proportion of high energy crashes than do the data sets from Michigan or NASS.

Year of the Crash

The first variable to be reported is the year of the crash. The number of vehicles involved in fatal crashes, the number of fire occurrences, the number of MHE fires, the raw percentage rate of occurrence of fire and MHE fire for cars, partitioned by year of the crash appears in Exhibits 1 and 2. Neither fire nor MHE fire exhibits an increasing trend or a decreasing trend over time for cars, light trucks, or vans. Since the vehicles in this study are restricted to 1978 and newer vehicles there are relatively few vehicles in the data base for early years of the study. The results are:

Exhibit 1
YEAR OF CRASH - 1978 MODEL YEAR AND LATER CARS

Year of Crash	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
1979	7165	168	2.34	54	0.75
1984	10061	246	2.45	88	0.87
1981	12889	303	2.35	109	0.85
1982	13248	284	2.41	88	0.69
1984	14902	351	2.36	117	0.79
1984	17638	397	2.25	112	0.63
1988	20121	403	2.00	109	0.53
1986	22859	552	2.41	167	0.73
1987	25575	626	2.46	193	0.75
1988	28031	716	2.55	192	0.69
1984	28583	666	2.33	178	0.62
1988	28655	726	2.53	194	0.69
1991	27325	746	2.73	197	0.72
1992	26546	667	2.51	157	0.59

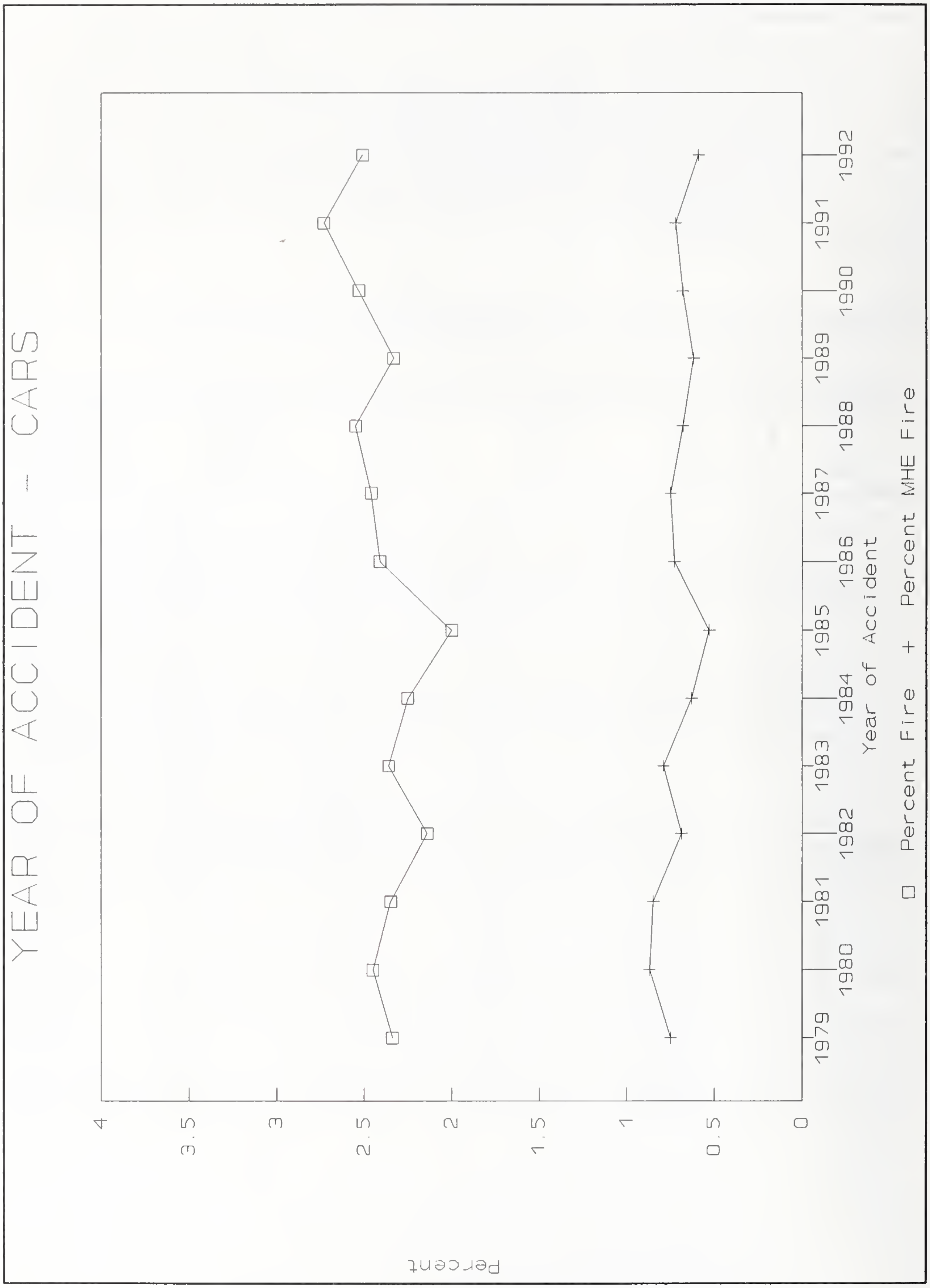

Exhibit 2
YEAR OF CRASH - CARS

There are relatively few 1978 and newer model year light trucks involved in fatal crashes (especially those with fire/MHE fire) in the early 1980's that one should not automatically conclude that there has been a significant decrease in the occurrence of fire or MHE fire. The results are in Exhibits 3 and 4.

Exhibit 3
YEAR OF CRASH - 1978 MODEL YEAR AND LATER LIGHT TRUCKS

Year of Crash	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
1979	2648	87	3.29	42	1.21
1980	3540	97	2.74	47	1.33
1981	4028	111	2.76	42	1.04
1982	3819	90	2.36	41	1.07
1983	4110	90	2.19	33	0.80
1984	4774	114	2.39	42	0.88
1985	5448	126	2.31	40	0.73
1986	6211	156	2.51	44	0.71
1987	6989	179	2.56	63	0.90
1988	8002	219	2.74	76	0.95
1989	8113	233	2.79	75	0.92
1990	8427	231	2.67	76	0.88
1991	9789	284	2.82	93	0.92
1992	9969	263	2.57	71	0.69

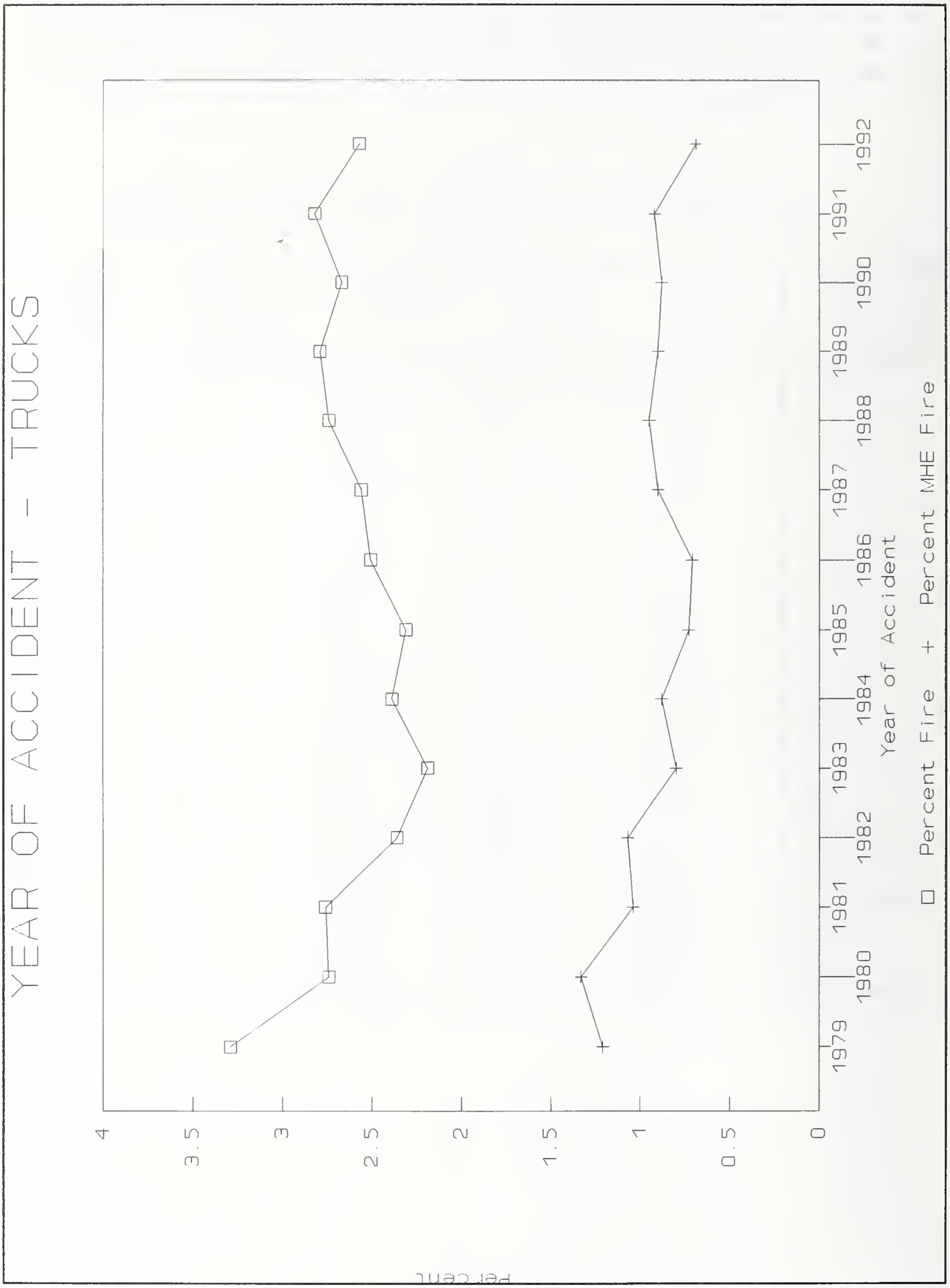

Exhibit 4
YEAR OF Crash - TRUCKS

There was no appreciable relationship between the year of the crash on the rate of occurrence of either fire or MHE fire for vans. Note that the sample size for vans is smaller than the sample size for light trucks. The results are in Exhibits 5 and 6.

Exhibit 5
YEAR OF CRASH - 1978 MODEL YEAR AND LATER VANS

Year of Crash	Vans in Fatal Crashes	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
1979	504	8	1.79	2	0.40
1980	633	10	1.58	3	0.47
1981	693	21	3.03	8	1.30
1982	637	12	1.88	4	0.63
1983	682	5	0.73	2	0.29
1984	890	18	2.13	8	0.40
1985	1063	18	1.68	5	0.47
1986	1173	31	2.64	9	0.77
1987	1511	29	1.92	9	0.60
1988	1729	42	2.43	15	0.87
1984	1991	39	1.97	4	0.20
1990	2072	35	1.69	12	0.58
1991	2059	40	1.94	10	0.49
1992	2292	46	2.01	14	0.61

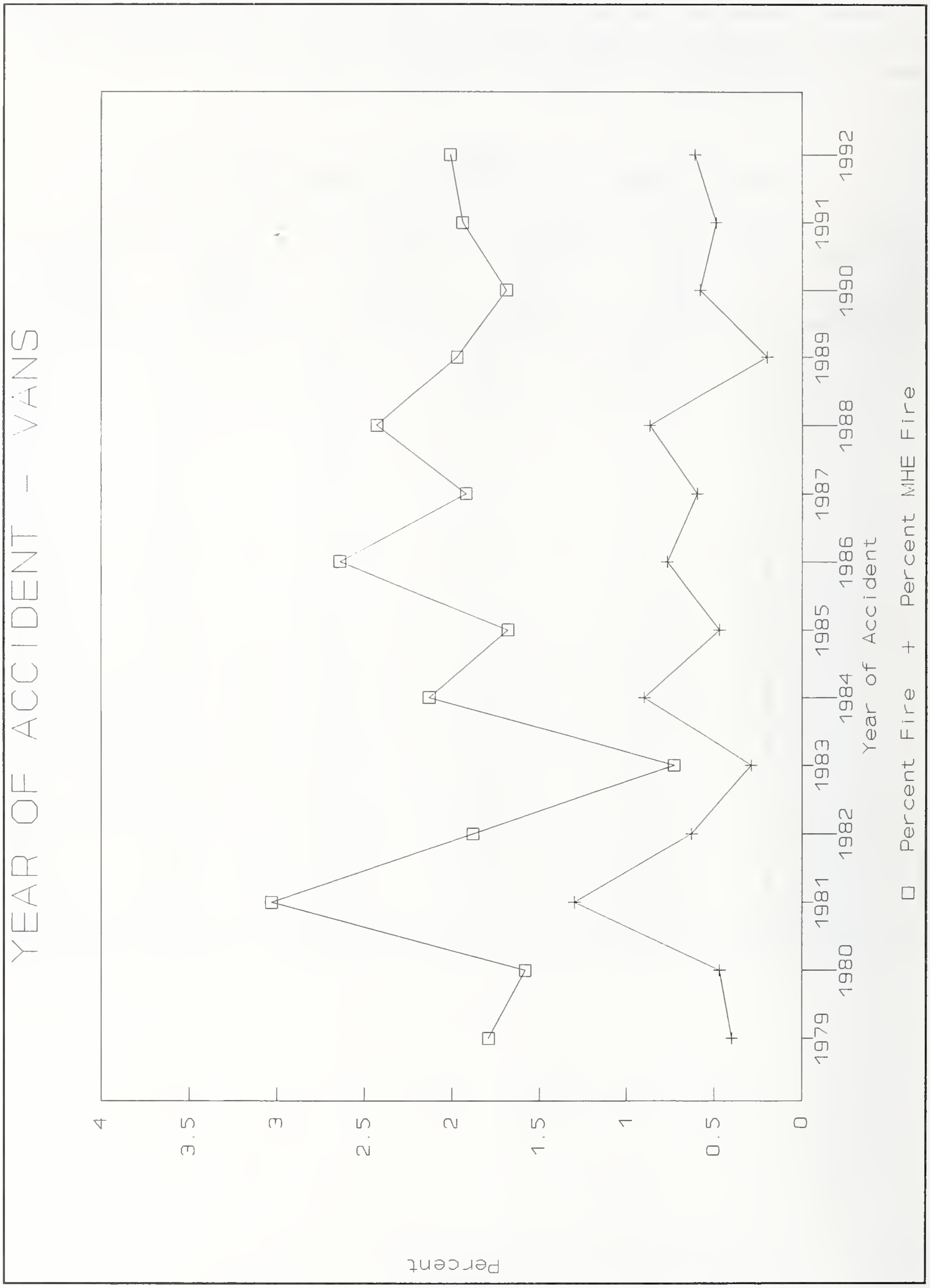

Exhibit 6
YEAR OF CRASH - VANS

Model Year of the Vehicle

The number of vehicles involved in fatal crashes, the number of fire occurrences, the number of MHE fires, the raw percentage rate of occurrence of fire and MHE fire for cars, light trucks and vans, by model year of the vehicle under analysis, appears below. The rate of fire by model year does not seem to exhibit a trend for cars. The rate of MHE fire shows an increase for older model years, increasing from a rate of 0.50 percent for model year 1990 to 0.88 percent for model year 1978. 1992 model year cars have the highest rate of MHE fire with a rate of 1.23 percent. However, only 1495 of the 1992 model year cars were involved in a fatal crash. The car statistical model for MHE fires shows that there is a small increase in the rate of MHE fire as the model year decreases. During the time frame of this study, front wheel drive and fuel injection have become popular options and fuel tanks have been placed in different locations of the vehicle. It is possible that better designs of the later model vehicles may contribute to a reduction of the fire rate, if so, it may be detected when model year is examined. The results for cars are in Exhibits 7 and 8.

Exhibit 7
MODEL YEAR - CARS

Model Year	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
1978	36180	947	2.62	319	0.88
1979	37310	1028	2.76	324	0.87
1980	29834	701	2.35	177	0.59
1981	25174	549	2.18	172	0.68
1982	20968	498	2.38	137	0.65
1983	19335	465	2.40	125	0.65
1984	23855	595	2.49	150	0.63
1985	21233	524	2.47	119	0.56
1986	19167	469	2.45	130	0.68
1987	16057	370	2.30	118	0.70
1988	13431	265	1.97	68	0.51
1989	9689	187	1.93	51	0.53
1990	5972	132	2.21	30	0.50
1991	3665	76	2.03	21	0.56
1992	1495	48	3.11	19	1.23

A. C. Malliaris, in his August 1990 paper, "Impact-Induced Car Fires-A Comprehensive Investigation", [Accident Analysis and Prevention, Vol. 23, Issue #4, pp 257-273] suggests

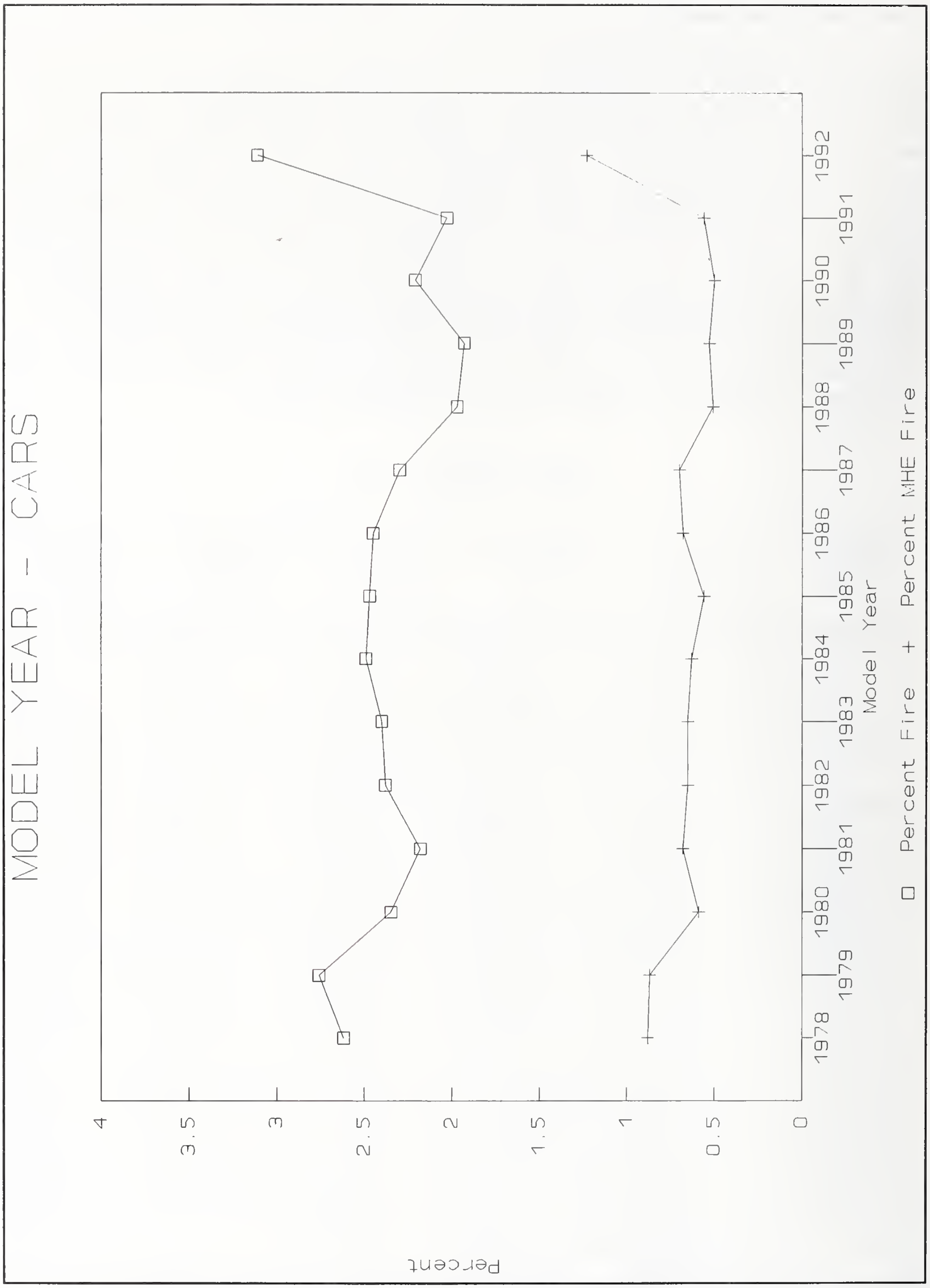

Exhibit 8
MODEL YEAR - CARS

that model year may be confounded with vehicle age. To examine this issue the analysis in Exhibit 7 was performed with vehicle age limited to four years as done by Malliaris and was then repeated limiting the age of the vehicles to two years. There was no appreciable change between limiting the age to four years and limiting the age to two years. The results of limiting age to four years appears in Exhibit 9. The Malliaris result which showed that the fire rate increases with older model years was not noted here. The differences in results between this effort and that of Malliaris seem to be due to differences in model years examined, using the entire nation as opposed to the single state of Michigan and using all crashes in Michigan rather than the fatal crashes of this effort.

Exhibit 9
MODEL YEAR, AGE LIMITED TO FOUR YEARS - CARS

Model Year	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
1978	13911	308	2.21	111	0.80
1979	16594	426	2.57	148	0.89
1980	13849	294	2.12	76	0.55
1980	11992	238	1.93	84	0.70
1982	10617	216	2.03	57	0.53
1984	10509	233	2.22	65	0.62
1984	14234	334	2.35	77	0.54
1989	14076	308	2.20	74	0.53
1989	14409	341	2.37	96	0.67
1987	13833	315	2.28	103	0.74
1988	13431	265	1.97	68	0.51
1989	9682	187	1.93	51	0.53
1990	5972	132	2.21	30	0.50
1991	3741	76	2.03	21	0.56
1992	1543	48	3.11	19	1.23

Neither the rate of fire nor the rate of MHE fire by model year exhibits an apparent trend for light trucks. Detailed modeling does not identify model year as a significant variable. The results are in Exhibits 10 and 11.

Exhibit 10
MODEL YEAR - LIGHT TRUCKS

Model Year	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
1978	10326	269	2.61	95	0.92
1979	11202	301	2.69	116	1.04
1980	6396	135	2.11	48	0.79
1981	5869	170	2.48	61	1.04
1982	5479	136	2.48	49	0.89
1983	5538	156	2.82	49	0.89
1984	7084	169	2.39	65	0.92
1985	6736	193	2.87	53	0.79
1986	7144	200	2.80	63	0.88
1987	5750	162	2.82	48	0.78
1988	5751	144	2.50	51	0.89
1989	4211	121	2.87	42	1.00
1990	2510	58	2.31	21	0.84
1991	1869	38	2.03	7	0.37
1992	697	14	2.01	4	0.59

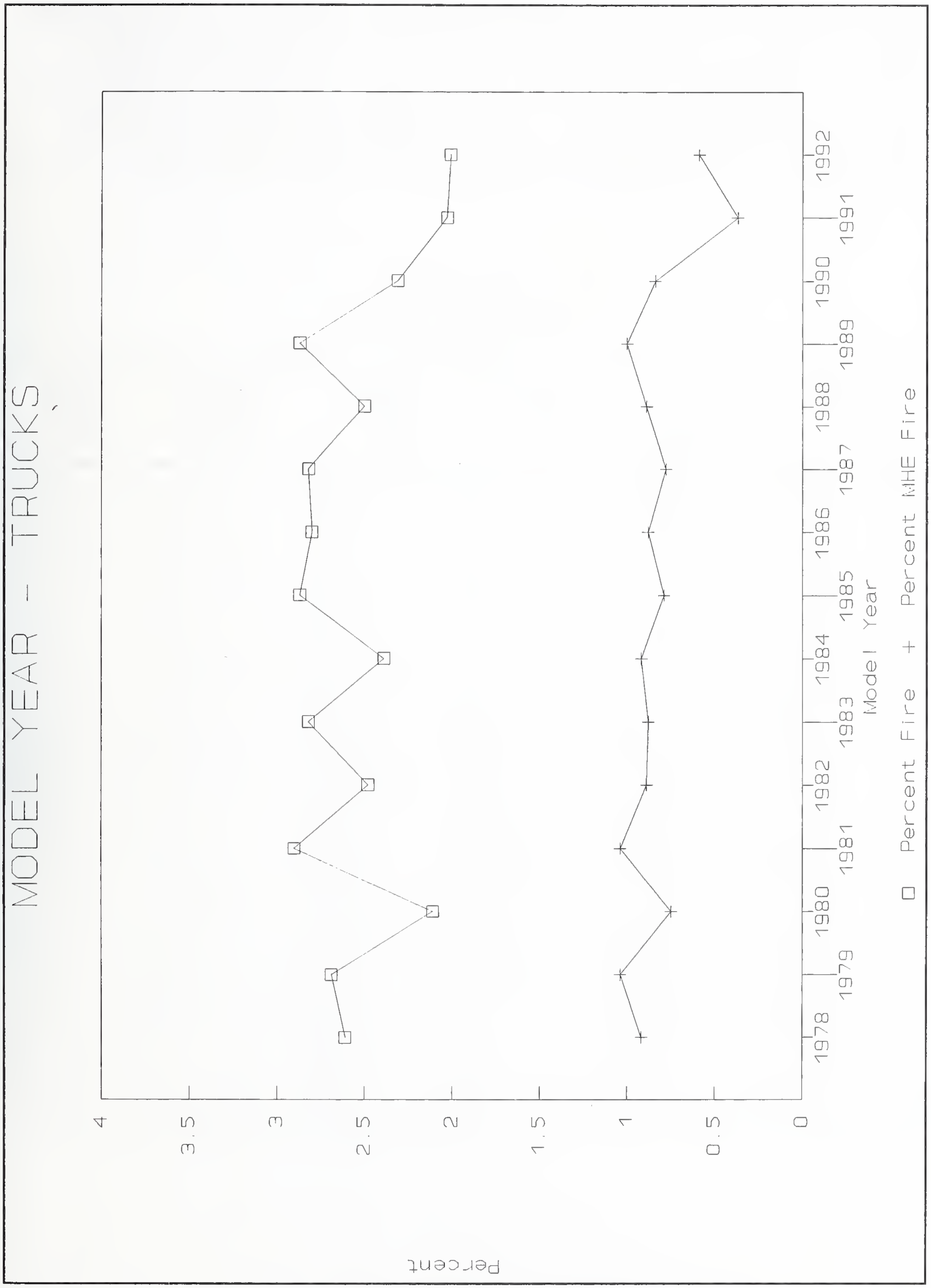

Exhibit 11
MODEL YEAR - TRUCKS

The number of fires among vans is relatively small when compared to cars and light trucks. There seems to be an indication that different model years have different rates of fire and MHE fire. Furthermore, the data suggest a decreasing trend in both the rates of fire and MHE fire, with respect to model year, i.e., earlier models have higher rates of occurrence. However, with relatively few events, i.e., fires and MHE fires, the "trend" is not well established. Statistical modeling of vans shows that older model years are expected to have a higher rate of most harmful event fires. The results are in Exhibits 12 and 13.

Exhibit 12
MODEL YEAR - VANS

Model Year	Vans in Fatal Crashes	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
1978	2244	46	2.05	19	0.85
1979	2308	50	2.17	15	0.85
1980	924	14	1.52	5	0.54
1981	835	14	1.68	7	0.84
1982	933	22	2.33	9	0.95
1983	933	15	1.61	2	0.21
1983	1396	35	2.51	18	0.79
1985	1632	46	2.82	7	0.84
1986	1655	33	1.99	8	0.54
1987	1423	23	1.62	8	0.56
1985	1193	22	1.61	6	0.50
1989	1090	18	1.65	6	0.37
1990	741	8	1.08	3	0.40
1991	390	8	2.05	1	0.26
1992	198	2	1.01	0	0.00

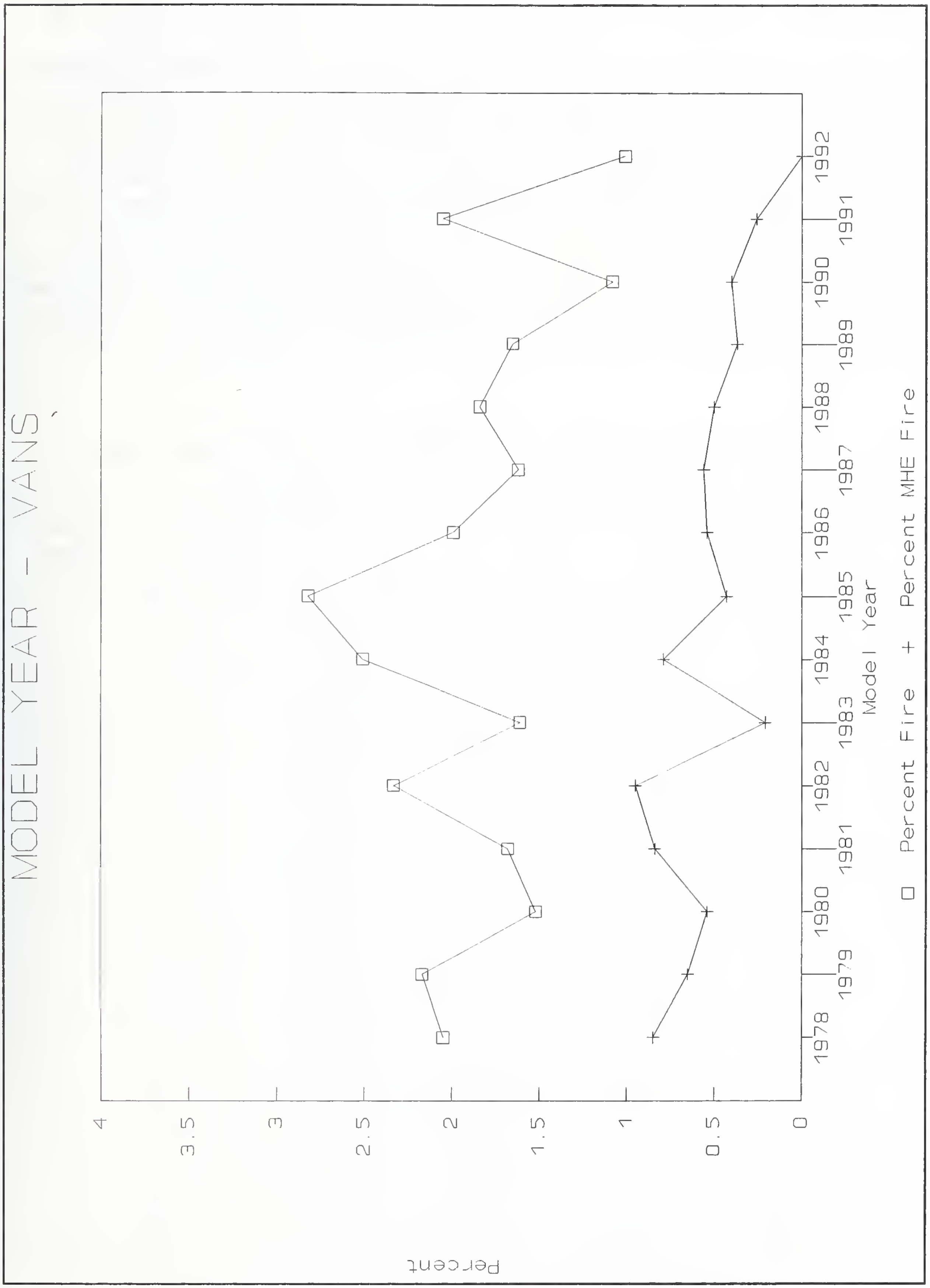

Exhibit 13
MODEL YEAR - VANS

Vehicle Age

The number of vehicles involved in fatal crashes, the number of fire occurrences, the number of MHE fires, the raw percentage rate of occurrence of fire and MHE for cars, light trucks and vans by age of the vehicle appears below. Exhibits 14 and 15 suggest that as cars age the likelihood of a fire increases. Detailed modeling of cars, calculates the odds ratio for fire as 1.031. That is, newer cars are expected to have fewer fires. The car statistical model for MHE fire does not identify vehicle age as a significant variable. Older cars may be driven more aggressively than new cars. However, data is not currently available to address this concern. Univariate analysis examines a single variable at a time, in this case age. Since the 1978 model year vehicles were introduced several changes have taken place in the design of cars. Anti-locking brakes, air bags and front wheel drive are now readily available, but were generally unavailable on 1978 model cars. The question arises if the

Exhibit 14
VEHICLE AGE in YEARS - 1978 MODEL YEAR AND LATER CARS

Car Age Years	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
0	32818	771	2.35	239	0.73
1	41410	917	2.21	263	0.64
2	35364	782	2.21	253	0.72
3	31300	650	2.08	160	0.51
4	27595	602	2.18	195	0.60
5	24156	594	2.46	164	0.6[illegible]
6	21404	556	2.60	164	0.77
7	18014	474	2.63	139	0.77
8	14979	410	2.74	113	0.75
9	12050	339	2.81	97	0.80
10	9384	267	2.85	77	0.82
11	6817	206	3.02	50	0.73
12	4401	142	3.23	40	0.91
13	2793	104	3.72	22	0.79
14	1115	40	3.59	9	0.81

changes in the model year causes the observed effect as cars age. To address this concern, the model years were grouped into five groups of three model years each. The percent of

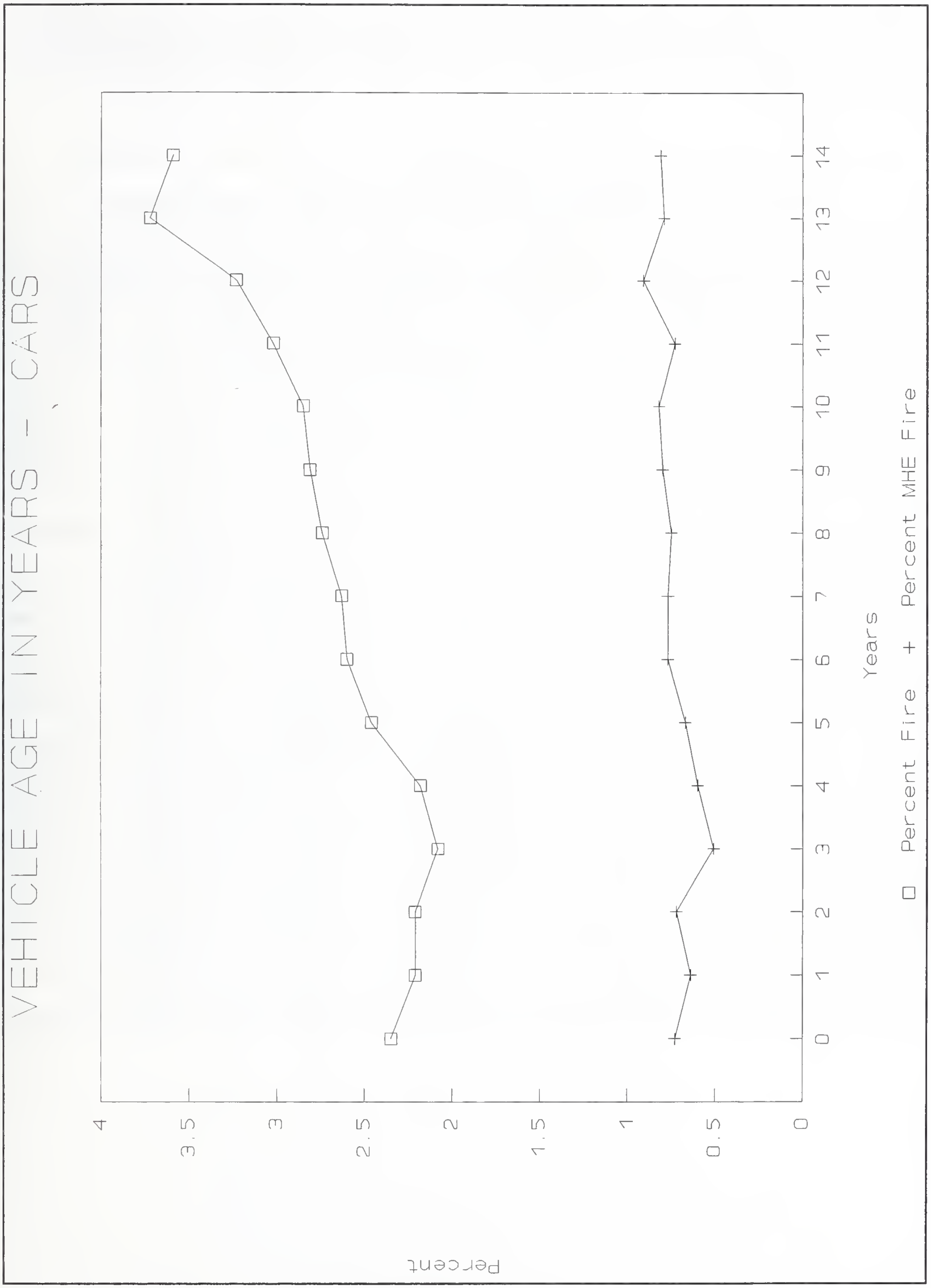

Exhibit 15
VEHICLE AGE in YEARS - CARS

car fires were then calculated for each group of model years by age. This approach seems to confirm the previous claim that as cars age they become more susceptible to fire if they are involved in a fatal crash. This result holds for all model year groups examined. The results are in Exhibit 16.

Exhibit 16
CAR PERCENT FIRE by AGE in YEARS and MODEL YEAR GROUP

Car Age Years	Model Year Group 78-80	Model Year Group 81-83	Model Year Group 84-86	Model Year Group 87-89	Model Year Group 90-92
0	2.91	2.31	2.37	2.22	2.50
1	2.36	2.13	2.24	2.18	1.98
2	2.36	2.10	2.27	2.18	2.31
3	2.21	1.93	2.31	1.78	
3	2.32	1.91	2.34	2.05	
5	2.36	2.28	2.71	2.47	
6	2.69	2.25	2.79		
7	2.33	2.57	3.22		
8	2.79	2.83	2.32		
9	2.91	2.68			
10	2.79	2.68			
11	3.14	2.53			
12	3.23				
13	3.72				
14	3.59				

There is no apparent increase or decrease of fires/MHE fires for light trucks with increasing age. The results appear in Exhibits 17 and 18.

Exhibit 17
VEHICLE AGE in YEARS - 1978 MODEL YEAR AND LATER LIGHT TRUCKS

Truck Age Years	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
0	10993	294	2.67	104	0.9[illegible]
1	14873	378	2.54	127	0.85
2	12504	322	2.[illegible]8	129	1.03
3	10310	267	2.[illegible]	96	0.93
4	8215	207	2.52	70	0.85
[illegible]	7013	183	2.61	47	0.6[illegible]
6	5688	157	2.76	45	0.79
7	4612	129	2.80	42	0.91
8	3574	42	2.57	42	0.90
9	2802	81	2.89	30	1.07
10	2015	46	2.23	13	0.93
11	1574	45	2.78	11	0.68
12	1112	29	2.54	13	1.14
13	820	26	3.07	6	0.71
14	345	11	3.09	4	1.12

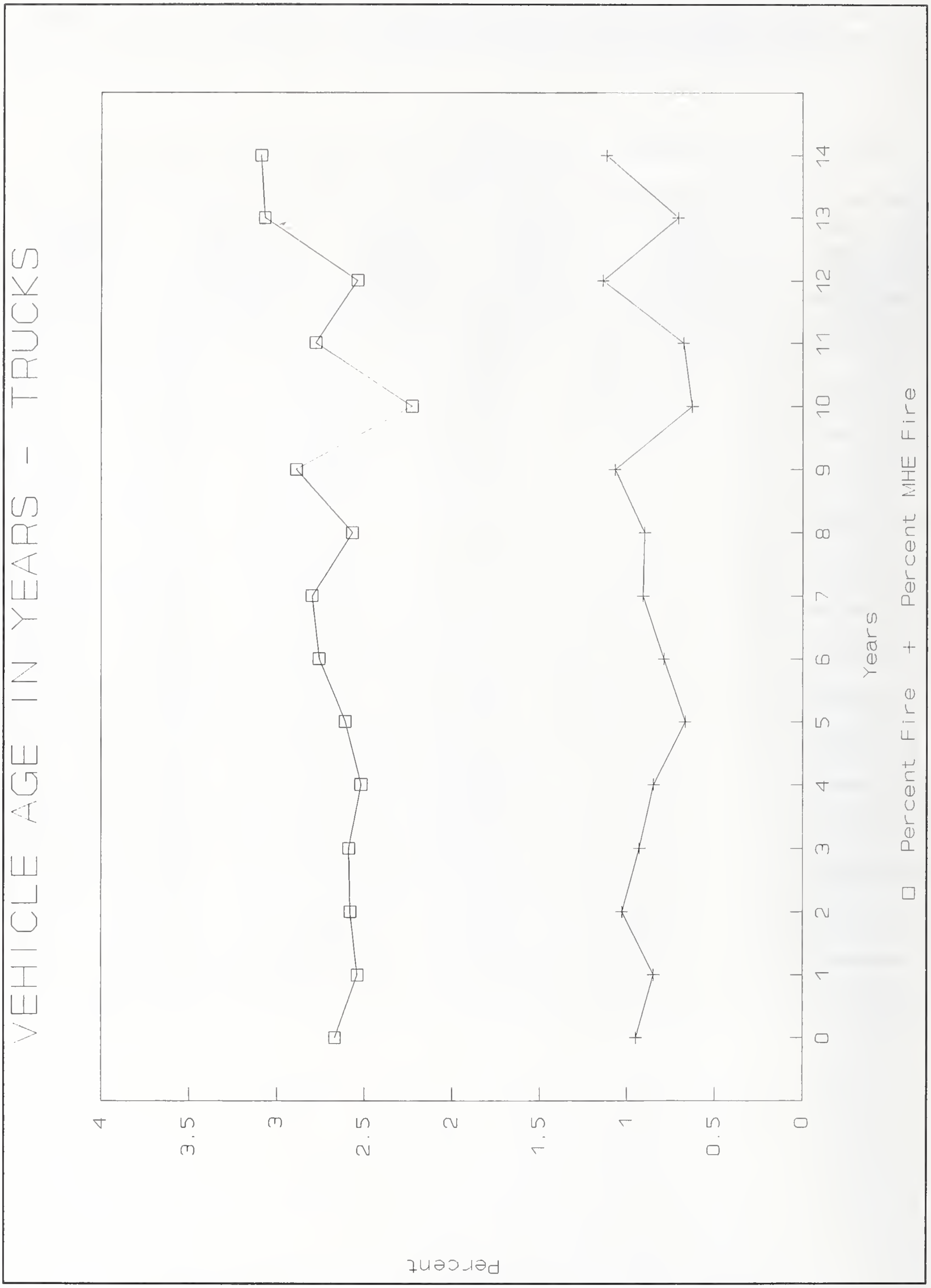

Exhibit 18
VEHICLE AGE in YEARS - TRUCKS

There is no appreciable increase or decrease of fires/MHE fires for vans with increasing age. Due to the small sample sizes, the rates are quite variable. The results are in Exhibits 19 and 20.

Exhibit 19
VEHICLE AGE in YEARS - 1978 MODEL YEAR AND LATER VANS

Van Age Years	Vans in Fatal Crashes	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
0	2316	45	1.94	8	0.35
57	3154	57	1.81	14	0.44
2	2676	52	1.94	22	0.82
3	2112	38	1.80	11	0.52
4	1739	36	2.07	7	0.40
5	1367	24	1.76	5	0.37
6	1159	25	2.16	12	1.04
7	924	17	1.84	6	0.65
8	663	15	2.26	6	0.90
9	559	18	3.22	7	1.25
10	385	13	3.39	4	1.04
11	324	5	1.54	1	0.31
12	256	3	1.17	1	0.39
13	188	7	3.72	2	1.06
14	98	1	1.02	0	0.00

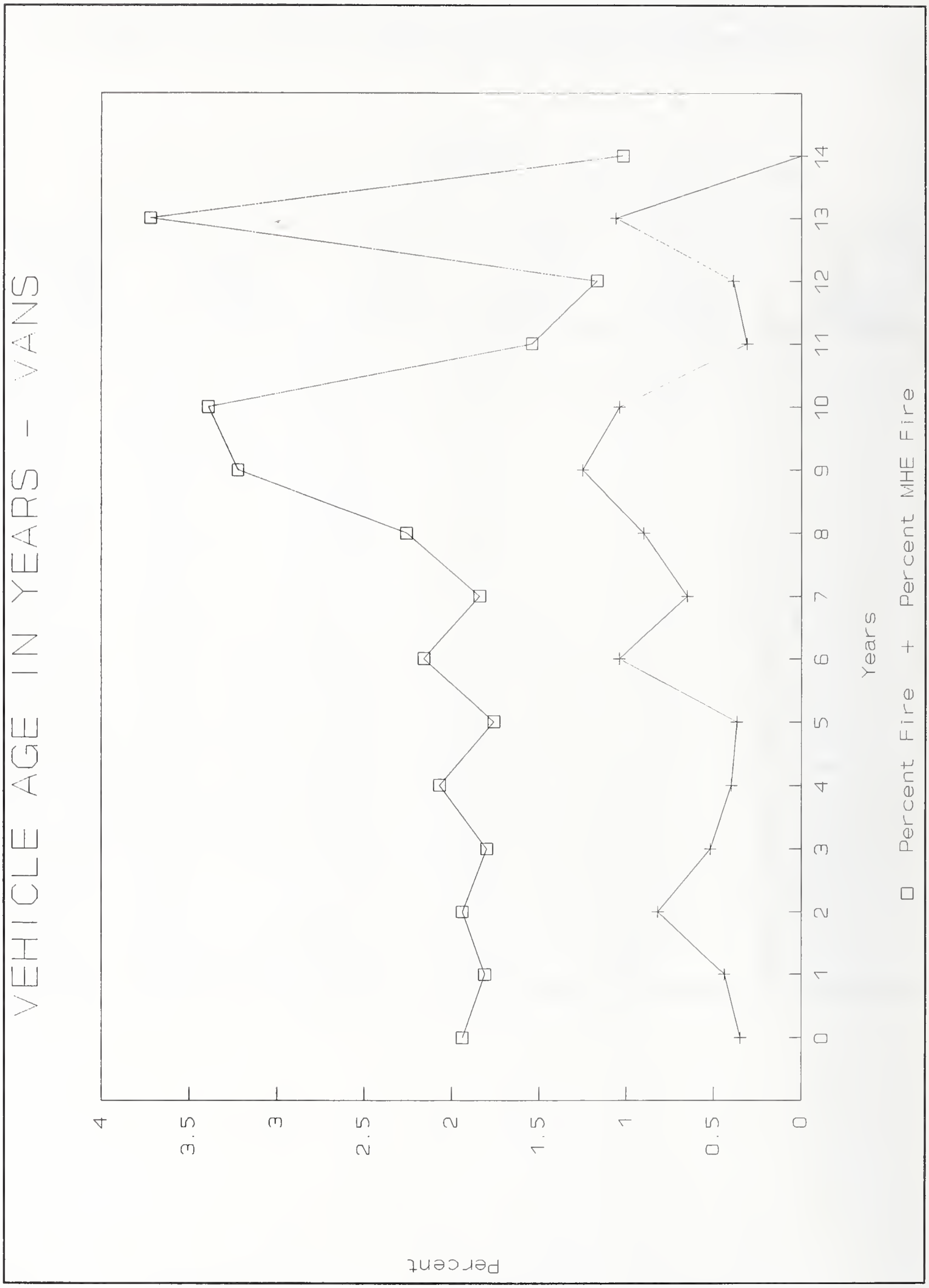

Exhibit 20
VEHICLE AGE in YEARS - VANS

Number of Vehicles Involved

The occurrence of fires/MHE fires for car single-vehicle fatal crashes is approximately 30/100 percent higher than for multiple-vehicle car fatal crashes. A total of 3114 crashes involving a single car and no other vehicle had fire. There were 3740 cars involving a car and at least one other vehicle, which need not be a car. A total of 1087 cars in single-vehicle car crashes were identified as having a fire as the MHE. A total of 867 cars in multiple-vehicle crashes were identified as having a fire as the MHE. In single vehicle crashes usually at least one occupant of the vehicle dies. In multiple vehicle crashes, many vehicles do not have an occupant that dies. By adding the columns of Exhibit 21 one finds that 283598 vehicles were involved in car crashes and 6854 cars experienced a fire. This produces a fire rate of 2.42 percent. The results are in Exhibit 21.

Exhibit 21
SINGLE-VEHICLE vs. MULTIPLE-VEHICLE CRASHES - CARS

Crash Complexity	Vehicles in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Single	110435	3114	2.82	1087	0.98
Multiple	173163	3740	2.16	867	0.50

The 95 percent upper and lower confidence limits[1] for categorical data were calculated for both fire and MHE fire. As a rough approximation, if the percentage for one level is within the 95 percent confidence level of another level then one can conclude that there is no measurable difference in the percentages (although to be certain, the complete statistical test, incorporating the standard errors of both estimates should be computed). The results are presented in Exhibit 22.

Exhibit 22
95 PERCENT CONFIDENCE LIMITS FOR
SINGLE-VEHICLE vs. MULTIPLE-VEHICLE CRASHES - CARS

Crash Complexity	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Single	2.72	2.82	2.92		0.92	0.98	1.04
Multiple	2.09	2.16	2.23		0.47	0.50	0.53

[1] Freund, John E., Mathematical Statistics, Englewood Cliffs, N.J. Prentice-Hall, Inc, 1962, Chapter 10, pp 232-233.

The occurrence of fires/MHE fires for truck crashes involving a single-vehicle is approximately 5/75 percent higher than truck crashes involving more than one vehicle. A total of 1036 crashes involving a single truck and no other vehicle had fire. There were 1244 crashes involving a truck and at least one other vehicle, which need not be a truck. A total of 452 light trucks in single-vehicle crashes were identified as having a fire as the MHE. There were 323 trucks in multiple-vehicle crashes that were identified as having a fire as the MHE, see Exhibits 23 and 24.

Exhibit 23
SINGLE-VEHICLE vs. MULTIPLE-VEHICLE CRASHES - LIGHT TRUCKS

Crash Complexity	Vehicles in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
Single	38502	1036	2.69	452	1.17
Multiple	48376	1244	2.57	323	0.67

Exhibit 24
95 PERCENT CONFIDENCE LIMITS FOR
SINGLE-VEHICLE vs. MULTIPLE-VEHICLE CRASHES - LIGHT TRUCKS

Crash Complexity	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Single	2.52	2.69	2.86		1.05	1.17	1.28
Multiple	2.42	2.57	2.72		0.60	0.67	0.75

The occurrence of fires/MHE fires for single-vehicle van crashes is approximately 5/100 percent higher than for vans in multiple-vehicle crashes. A total of 130 crashes involving a single van and no other vehicle had fire. There were 226 crashes involving a van and at least one other vehicle, which need not be a van. A total of 55 crashes involving a single van and no other vehicle were identified as having a fire as the MHE. A total of 51 crashes, involving a van and at least one other vehicle, which need not be a van, were identified as having a fire as the MHE, see Exhibits 25 and 26.

Exhibits 25
SINGLE-VEHICLE vs. MULTIPLE-VEHICLE CRASHES - VANS

Crash Complexity	Vehicles in Fatal Crashes	Number Fire Vans	Present Fire Vans	Number MHEF Vans	Percent MHEF Van
Single	6284	130	2.07	55	0.88
Multiple	11635	226	1.94	51	0.44

Exhibits 26
95 PERCENT CONFIDENCE LIMITS FOR
SINGLE-VEHICLE vs. MULTIPLE-VEHICLE CRASHES - VANS

Crash Complexity	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Single	1.72	2.07	2.42		0.64	0.88	1.11
Multiple	1.69	1.94	2.19		0.32	0.44	0.56

Weight of Cars

The Fatal Accident Reporting System (FARS) collects information on the weight of cars involved in fatal crashes. Vehicle weight is not generally available for light trucks or vans. The variable car weight has been partitioned into six classes based on previous applications (e.g., "*Passenger Car Weight and Injury Severity in Single-vehicle Nonrollover Crashes*", Partyka and Boehly, 1989, ESV Report 89-2b-O-005 and "*Development of Databases in Support of an Analysis of Fire Incidence Using the Fatal Accident Reporting System*", Walz and Klein, Sep. 14, 1993). This partition is used for this analysis and is defined in Exhibit 27 as:

Exhibit 27
CAR WEIGHT CLASSES

Class	Weight Range in Pounds
Class 1	Car Weight < 1950
Class 2	1950 ≤ Car Weight < 2450
Class 3	2450 ≤ Car Weight < 2950
Class 4	2950 ≤ Car Weight < 3450
Class 5	3450 ≤ Car Weight < 3950
Class 6	3950 ≤ Car Weight

The data suggest that as the weight of the car increases, the rate of fire also increases. To have a fatality in a heavier car, more energy is usually required, which in turn requires a more severe crash. A more severe crash, in turn, may lead to higher occurrences of fires. The column headed Number Fatal Cars refers to the number of cars involved in a fatal crash (however, not all cars experienced an occupant fatality). The results of the partition appear in Exhibit 28 and 29.

Exhibit 28
WEIGHT CLASS - CARS

Weight Class	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Class 1	19577	361	1.84	118	0.60
Class 2	72437	1565	2.16	361	0.61
Class 3	65296	1555	2.38	401	0.61
Class 4	66474	1876	2.82	527	0.79
Class 5	29662	752	2.54	230	0.78
Class 6	30138	745	2.47	237	0.79

Exhibit 29
95 PERCENT CONFIDENCE LIMITS FOR WEIGHT CLASS - CARS

Weight Class	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Class 1	1.66	1.84	2.03		0.49	0.60	0.71
Class 2	2.05	2.16	2.27		0.55	0.60	0.67
Class 3	2.26	2.38	2.50		0.55	0.61	0.67
Class 4	2.70	2.82	2.95		0.73	0.79	0.86
Class 5	2.36	2.54	2.71		0.68	0.78	0.88
Class 6	2.30	2.47	2.65		0.69	0.79	0.89

Area of Damage

The area where the damage to the vehicle occurred was partitioned into five mutually exclusive ranges: rollover, front, rear, side, and other. If the vehicle experienced a rollover, despite what other damage occurred, the vehicle was coded as a rollover.
Over half the cars involved in fatal crashes received damage to the front of the vehicle and there were more fire/MHE fires reported for cars with damage in the front than any other area. However, the rate of fire occurrence, i.e., the percentage fire/MHE fire, for cars with damage to the front, is the second lowest for both fire and MHE fire. Relatively few cars in fatal crashes have damage to the rear of the vehicle. But when the rear of a car is involved, one experiences the highest rate of occurrence of both fire/MHE fire. It is important to compare this exhibit with the corresponding exhibits for light trucks and vans. Note that cars are more likely to have a fire/MHE fire if the rear is involved compared to light trucks or vans, i.e., cars are more susceptible to fire when the rear is involved than are light trucks and vans. This may be due to the location of the fuel tank, especially vs. pickup trucks, wherein the fuel tanks are generally located below the cab and the bed, often between the frame rails. The rates of occurrence of fire/MHE fire for cars experiencing damage to the rear are 5.38 percent/2.27 percent, respectively. These are the highest rates for any area of damage. Most cars experience damage to the front of the vehicle, and these frontally damaged vehicles experience the greatest number of fires (3275)/MHE fires (839), with rates of occurrence of 2.13 percent/0.55 percent, respectively, see Exhibits 30 and 31.

Exhibit 30
AREA OF DAMAGE - CARS

Damaged Area	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Rollover	43718	1436	3.28	446	1.02
Front	153610	3275	2.13	839	0.55
Rear	11903	640	5.38	270	2.27
Side	63569	1167	1.84	268	0.42
Other	10798	336	3.11	131	1.21

Exhibit 31
95 PERCENT CONFIDENCE LIMITS FOR AREA OF DAMAGE - CARS

Damaged Area	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Rollover	3.12	3.28	3.45		0.93	1.02	1.11
Front	2.06	2.13	2.20		0.51	0.55	0.59
Rear	4.98	5.38	5.78		2.00	2.27	2.53
Side	1.73	1.84	1.94		0.37	0.42	0.47
Other	2.79	3.11	3.44		1.00	1.21	1.41

The area of damage above can be further partitioned by weight class. This refined partition is only available for cars, see Exhibits 32, 33, 34, and 35. The rate of fire and MHE fire for rollover and cars with damage to the rear shows substantial variation by weight class. Rollovers, of weight class 5, have the highest rate for fire 5.33 percent and MHE fire 2.08 percent. Cars with damage to the rear of weight class 4 have the highest rate of fire 6.16 percent and MHE fire 2.62 percent.

Exhibit 32
OCCURRENCE OF FIRE - CARS
AREA OF DAMAGE PARTITIONED BY WEIGHT CLASS

Weight Class	Rollover	Front	Rear	Side	Other
Class 1	84	164	43	53	17
Class 2	312	785	130	261	77
Class 4	331	704	163	287	70
Class 4	407	904	169	327	69
Class 5	146	378	67	116	45
Class 6	156	340	68	123	58
Total	1436	3275	640	1167	336

Exhibit 33
PERCENT OF FIRE - CARS
AREA OF DAMAGE PARTITIONED BY WEIGHT CLASS

Weight Class	Rollover	Front	Rear	Side	Other
Class 1	2.19	1.65	4.97	1.26	2.38
Class 2	2.38	2.12	4.53	1.53	3.28
Class 4	2.99	2.10	5.85	1.76	3.30
Class 4	4.61	2.38	6.16	2.24	2.95
Class 5	5.33	2.03	5.24	1.95	4.20
Class 6	3.75	2.06	5.05	2.08	2.63
Total	3.28	2.13	5.38	1.82	3.11

Exhibit 34
OCCURRENCE OF MOST HARMFUL EVENT FIRE - CARS
AREA OF DAMAGE PARTITIONED BY WEIGHT CLASS

Weight Class	Rollover	Front	Rear	Side	Other
Class 1	35	51	18	9	5
Class 2	102	206	56	49	28
Class 3	77	162	67	64	31
Class 4	117	220	72	90	28
Class 5	57	101	30	20	22
Class 6	58	99	27	36	19
Total	446	839	270	268	131

Exhibit 35
PERCENT MOST HARMFUL EVENT FIRE - CARS
AREA OF DAMAGE PARTITIONED BY WEIGHT CLASS

Weight Class	Rollover	Front	Rear	Side	Other
Class 1	0.91	0.58	2.08	0.21	0.70
Class 2	0.78	0.56	1.95	0.29	1.19
Class 3	0.70	0.48	2.08	0.40	1.46
Class 4	1.33	0.58	2.62	0.62	1.20
Class 5	2.08	0.54	2.35	0.40	2.05
Class 6	1.39	0.60	2.08	0.61	0.77
Total	1.02	0.55	2.27	0.42	1.21

The rates of occurrence of fire/MHE fire for light trucks experiencing damage to the rear are 1.87 percent/0.61 percent respectively. These are the lowest rates for any area of damage. Unlike cars, light trucks with damage to the rear experience relatively few fires. Most trucks experience damage to the front of the vehicle, and these front-damage crashes result in the greatest number of fires and MHE fires, 1270/419. The rates of occurrence of 2.70 percent/0.89 percent respectively, see Exhibits 36 and 37.

Exhibit 36
AREA OF DAMAGE - LIGHT TRUCKS

Damaged Area	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
Rollover	23450	603	2.57	208	0.89
Front	47101	1270	2.70	419	0.89
Rear	2788	52	1.87	17	0.61
Side	10120	271	2.68	98	0.97
Other	3419	84	2.46	33	0.97

Exhibit 37
95 PERCENT CONFIDENCE LIMITS FOR AREA OF DAMAGE - LIGHT TRUCKS

Damaged Area	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Rollover	2.35	2.57	2.79		0.76	0.89	1.02
Front	2.54	2.70	2.85		0.80	0.89	0.98
Rear	1.35	1.87	2.43		0.30	0.61	0.93
Side	2.35	2.68	3.01		0.77	0.97	1.17
Other	1.92	2.46	2.98		0.63	0.97	1.31

There are approximately twelve times as many fires/MHE fires involving vans with damage to the front as vans involving rear damage. However, the rates of occurrence of fire/MHE fire are somewhat higher for vehicles with rear damage vs. front damage, namely, 2.73 percent/0.76 percent vs. 1.81 percent/0.54 percent, see Exhibits 38 and 39.

Exhibit 38
AREA OF DAMAGE - VANS

Damaged Area	Vans in Fatal Crashes	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
Rollover	3021	88	2.81	25	0.83
Front	11298	205	1.81	61	0.54
Rear	917	25	2.73	7	0.76
Side	2008	34	1.69	10	0.50
Other	675	7	1.04	3	0.44

Exhibit 39
95 PERCENT CONFIDENCE LIMITS FOR AREA OF DAMAGE - VANS

Damaged Area	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Rollover	2.22	2.81	3.41		0.51	0.83	1.15
Front	1.56	1.81	2.06		0.40	0.54	0.67
Rear	1.64	2.73	3.81		0.18	0.76	1.34
Side	1.11	1.69	2.27		0.19	0.50	0.82
Other	0.25	1.04	1.83		0.00	0.44	0.95

Object Struck

The kinematics of a crash are dependent on the type of object struck by the vehicle. Objects were partitioned into five categories: vehicle, narrow, fixed, other and overturn. Telephone poles are examples of narrow objects. A wall or fixed barrier is an example of a fixed object.

Narrow objects have the highest rate of fire/MHE fire for cars, namely 4.63 percent/1.62 percent, respectively. This may be due to the degree of penetration associated with striking narrow object, compared to striking other fixed objects or vehicles. There are about 2.8 times as many fires (3655) when a car struck another vehicle compared to striking a narrow object (1303). However, the rate of occurrence of a fire, when striking a narrow object, 4.63 percent, is approximately twice as high as when a car struck another vehicle, 2.20 percent. There were almost twice as many cases of a car striking another vehicle where a fire was judged as the MHE (850) as there were cars striking a narrow object (456). However, the rate of occurrence of a MHE fire for cars striking a narrow object is 1.62

percent, more than three times the rate for striking another vehicle, 0.51 percent. The results appear in Exhibits 40 and 41.

Exhibit 40
OBJECT STRUCK - CARS

Object Struck	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Vehicle	166511	3655	2.20	850	0.51
Narrow	28165	1303	4.63	456	1.62
Fixed	33257	1435	4.31	517	1.55
Other	40638	223	0.55	63	0.16
Overturn	14985	237	1.58	68	0.45

Exhibit 41
95 PERCENT CONFIDENCE LIMITS FOR OBJECT STRUCK - CARS

Object Struck	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Vehicle	2.14	2.20	2.27		0.48	0.51	0.55
Narrow	4.39	4.63	4.89		1.47	1.62	1.76
Fixed	4.10	4.31	4.53		1.42	1.55	1.68
Other	0.48	0.55	0.62		0.12	0.16	0.20
Overturn	1.39	1.58	1.76		0.35	0.45	0.55

Considering objects struck by light trucks, narrow objects have the highest rate of fire/MHE fire, namely 5.96 percent/2.84 percent, respectively. There are about three times as many fires (1224) when a truck struck another vehicle compared to when it struck a narrow object (414). However, the rate of occurrence of a fire when striking a narrow object, 5.96 percent, is more that twice as high as when a truck struck another vehicle, 2.61 percent. There were 60 percent more occurrences of a truck striking another vehicle where a fire was judged as the MHE (319) as there were light trucks striking a narrow object (197). However, the rate of occurrence of a MHE fire for light trucks striking a narrow object, 2.84 percent, is more than four times the rate for striking another vehicle, 0.68 percent. The results are in Exhibit 42 and 43:

Exhibit 42
OBJECT STRUCK - LIGHT TRUCKS

Object Struck	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
Vehicle	46936	1224	2.61	414	0.68
Narrow	6941	414	5.96	197	2.84
Fixed	10557	446	4.22	197	1.87
Other	12707	90	0.71	25	0.20
Overturn	9722	106	1.09	37	0.38

Exhibit 43
95 PERCENT CONFIDENCE LIMITS FOR OBJECT STRUCK - LIGHT TRUCKS

Object Struck	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Vehicle	2.46	2.61	2.76		0.60	0.68	0.76
Narrow	5.35	5.96	6.55		2.44	2.84	3.27
Fixed	3.81	4.22	4.63		1.59	1.87	2.15
Other	0.56	0.71	0.86		0.12	0.20	0.28
Overturn	0.85	1.09	1.31		0.25	0.38	0.51

Considering objects struck by vans, narrow objects have the highest rate of fire/MHE fire, namely 6.18 percent/3.15 percent, respectively. There are about four times as many fires (219) when a van struck another vehicle than a narrow object (49). However, the rate of occurrence of a fire, when a van struck a narrow object, 6.18 percent, is approximately 3 times as great as when a van struck another vehicle, 1.97 percent. There were almost twice the number cases of a van striking another vehicle where a fire was judged as the MHE (48) as there were when vans struck a narrow object (25). However, the rate of occurrence of a MHE fire for vans having struck a narrow object, 3.15 percent, was over seven times the rate of a van striking another vehicle, 0.43 percent. The results are contained in Exhibits 44 and 45.

Exhibit 44
OBJECT STRUCK - VANS

Object Struck	Vans in Fatal Crashes	Number Fire Vans	Percent Fire	Number MHEF Vans	Percent MHEF
Vehicle	11113	219	1.97	48	0.43
Narrow	793	49	6.18	25	3.15
Fixed	1354	57	4.21	23	1.70
Other	3580	19	0.53	7	0.20
Overturn	1077	12	1.11	3	0.28

Exhibit 45
95 PERCENT CONFIDENCE LIMITS FOR OBJECT STRUCK - VANS

Object Struck	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Vehicle	1.71	1.97	2.24		0.30	0.43	0.55
Narrow	4.50	6.18	7.87		1.91	3.15	4.38
Fixed	3.13	4.21	5.29		1.03	1.73	2.43
Other	0.29	0.53	0.78		0.05	0.20	0.35
Overturn	0.47	1.11	1.74		0.00	0.28	0.60

The preceding data can be partitioned by both Object Struck and Area of Damage. By definition the object struck is the first object struck or an overturn. Thus, virtually all coded overturns are also coded as rollovers, but all rollovers that occur after a vehicle has struck an object are not necessarily coded as overturns. Note that the greatest number of occurrences of fires are vehicle-to-vehicle crashes with damage to the front, rear and side. However, in the case of a rollover, a vehicle is most likely to strike a fixed object. In this case the number of occurrences by damaged area is highly dependent on the object struck. That is, there is a statistical interaction between object struck and area of damage. The results of this partition appear in Exhibits 46 through 51.

Exhibit 46
OCCURRENCE OF FIRE - CARS
OBJECT STRUCK Partitioned by AREA OF DAMAGE

Damaged Area	Vehicle	Narrow	Fixed	Other	Overturn
Rollover	342	260	591	24	219
Front	1928	649	593	101	4
Rear	558	37	41	3	1
Side	682	294	139	51	1
Other	145	63	71	44	12
Total	3655	1303	1435	223	237

Exhibit 47
OCCURRENCE OF MOST HARMFUL EVENT FIRE - CARS
OBJECT STRUCK Partitioned by AREA OF DAMAGE

Damaged Area	Vehicle	Narrow	Fixed	Other	Overturn
Rollover	86	38	207	7	58
Front	367	208	208	14	1
Rear	233	18	18	1	9
Side	126	85	46	41	0
Other	38	18	48	46	9
Total	850	456	517	63	68

Exhibit 48
OCCURRENCE OF FIRE - LIGHT TRUCKS
OBJECT STRUCK Partitioned by AREA OF DAMAGE

Damaged Area	Vehicle	Narrow	Fixed	Other	Overturn
Rollover	215	78	198	11	101
Front	769	249	202	48	2
Rear	45	2	2	3	0
Side	156	67	31	17	0
Other	39	18	13	11	3
Total	1224	414	446	90	106

Exhibit 49
OCCURRENCE OF MOST HARMFUL EVENT FIRE - LIGHT TRUCKS
OBJECT STRUCK Partitioned by AREA OF DAMAGE

Damaged Area	Vehicle	Narrow	Fixed	Other	Overturn
Rollover	56	30	85	4	33
Front	189	124	94	10	2
Rear	14	1	1	1	0
Side	50	35	11	2	0
Other	10	7	6	8	2
Total	319	197	197	25	37

Exhibit 50
OCCURRENCE OF FIRE - VANS
OBJECT STRUCK Partitioned by AREA OF DAMAGE

Damaged Area	Vehicle	Narrow	Fixed	Other	Overturn
Rollover	37	9	24	3	12
Front	134	32	30	5	0
Rear	22	2	1	0	0
Side	25	3	1	5	0
Other	1	3	1	2	0
Total	219	49	57	19	12

Exhibit 51
OCCURRENCE OF MOST HARMFUL EVENT FIRE - VANS
OBJECT STRUCK Partitioned by AREA OF DAMAGE

Damaged Area	Vehicle	Narrow	Fixed	Other	Overturn
Rollover	10	2	3	2	3
Front	26	18	15	2	0
Rear	6	[illegible]	0	0	0
Side	5	3	0	2	0
Other	1	1	0	1	0
Total	48	25	23	7	3

Rollover

The effect of a rollover vs. no rollover was examined as a dichotomous variable, i.e., only two values. No rollover is the union of the front, rear, side, and other cases, from the Area of Damage analysis. Cars that experience a rollover have approximately a 45/60 percent higher rate of occurrence of fires/MHE fires. A total of 1436 cars with a rollover experienced a fire. There were 5418 cars that had a fire but did not experience a rollover. There were 446 cars that experienced a rollover, which were identified as having a fire as the MHE. A total of 1508 cars did not experience a rollover and were identified as having a fire as the MHE. Exhibits 52 and 53 contain the results.

Exhibit 52
ROLLOVER - CARS

Rollover Status	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Rollover	43718	1436	3.28	446	1.02
No Rollover	239880	5418	2.26	1509	0.63

Exhibit 53
95 PERCENT CONFIDENCE LIMITS FOR ROLLOVER - CARS

Rollover Status	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Rollover	3.12	3.28	3.45		0.93	1.02	1.11
No Rollover	2.20	2.26	2.32		0.60	0.63	0.66

In the case of cars that rollover the principal impact point, i.e. the point that produced the most property damage or personal injury is of interest. The principal impact point has been partitioned into the following areas: front, rear, side, non-collision, top, undercarriage, underride, override and other. The results of the partition of rollover appear in Exhibit 54.

Exhibit 54
ROLLOVERS PARTITIONED BY PRINCIPAL IMPACT POINT - CARS

Principal Impact Point	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Front	14546	696	4.78	212	1.08
Rear	1379	70	5.08	24	1.74
Side	6757	214	3.17	57	0.84
Non-collision	12081	180	1.50	46	0.38
Top	6399	180	2.81	69	1.08
Undercarriage	1056	36	3.41	20	1.08
Underride	21	3	14.29	2	9.52
Override	15	0	0	0	0
Unknown	1464	56	3.83	16	1.08
Total	43718	1436	3.28	446	1.02

There is no appreciable change in the rate of occurrence of fires/MHE fire whether or not a truck experiences a rollover. A total of 603 light trucks experienced a rollover and caught fire. There were 1677 trucks that had a fire but did not experience a rollover. A total of 208 light trucks that experienced a rollover were identified as having a fire as the MHE. A total of 567 light trucks did not experience a rollover but were identified as having a fire as the MHE. See Exhibits 55 and 56 for the findings.

Exhibit 55
ROLLOVER - LIGHT TRUCKS

Rollover Status	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
Rollover	23450	603	2.57	208	0.89
No Rollover	63428	1677	2.64	567	0.89

Exhibit 56
95 PERCENT CONFIDENCE LIMITS FOR ROLLOVER - LIGHT TRUCKS

Rollover Status	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Rollover	2.35	2.57	2.79		0.76	0.89	1.02
No Rollover	2.51	2.64	2.77		0.82	0.89	0.97

Vans that experienced a rollover have a higher rate of occurrence of fires/MHE fires by approximately 50 percent. A total of 85 vans experienced a rollover and had a fire. There were 271 vans that had a fire but did not experience a rollover. There were 25 vans that experienced rollovers that were also identified as having a fire as the MHE. A total of 81 vans did not experience a rollover and were identified as having a fire as the MHE. Exhibits 57 and 58 contain the results.

Exhibit 57
ROLLOVER - VANS

Rollover Status	Vans in Fatal Crashes	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
Rollover	3021	85	2.81	25	0.83
No Rollover	14898	271	1.82	81	0.64

Exhibit 58
95 PERCENT CONFIDENCE LIMITS FOR ROLLOVER - VANS

Rollover Status	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Rollover	2.22	2.81	3.41		0.51	0.83	1.15
No Rollover	1.60	1.82	2.04		0.42	0.54	0.66

Posted Speed Limit

The number of fire occurrences, the number of MHE fires, the raw percentage rate of occurrence of fire and MHE fire for cars, light trucks and vans by posted speed limit appears below. The exhibits for cars suggests that as the speed limit increases the likelihood of a fire/MHE fire also rises. The results are found in Exhibits 59 and 60. Note that largest percent fire rate of Exhibit 59 is 4.13 but the upper bound of Exhibit 60 is 4.00 which results in truncation.

Exhibit 59
SPEED LIMIT - CARS

Speed Limit MPH	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
15	273	2	0.73	1	0.37
20	569	11	1.93	6	1.05
25	11007	149	1.35	40	0.36
30	21229	307	1.45	78	0.35
30	31534	529	1.68	139	0.44
45	20959	369	1.76	149	0.50
45	33548	596	1.78	153	0.46
50	16991	372	2.19	103	0.61
55	130538	4051	3.10	1208	0.93
65	7077	283	4.13	77	1.09

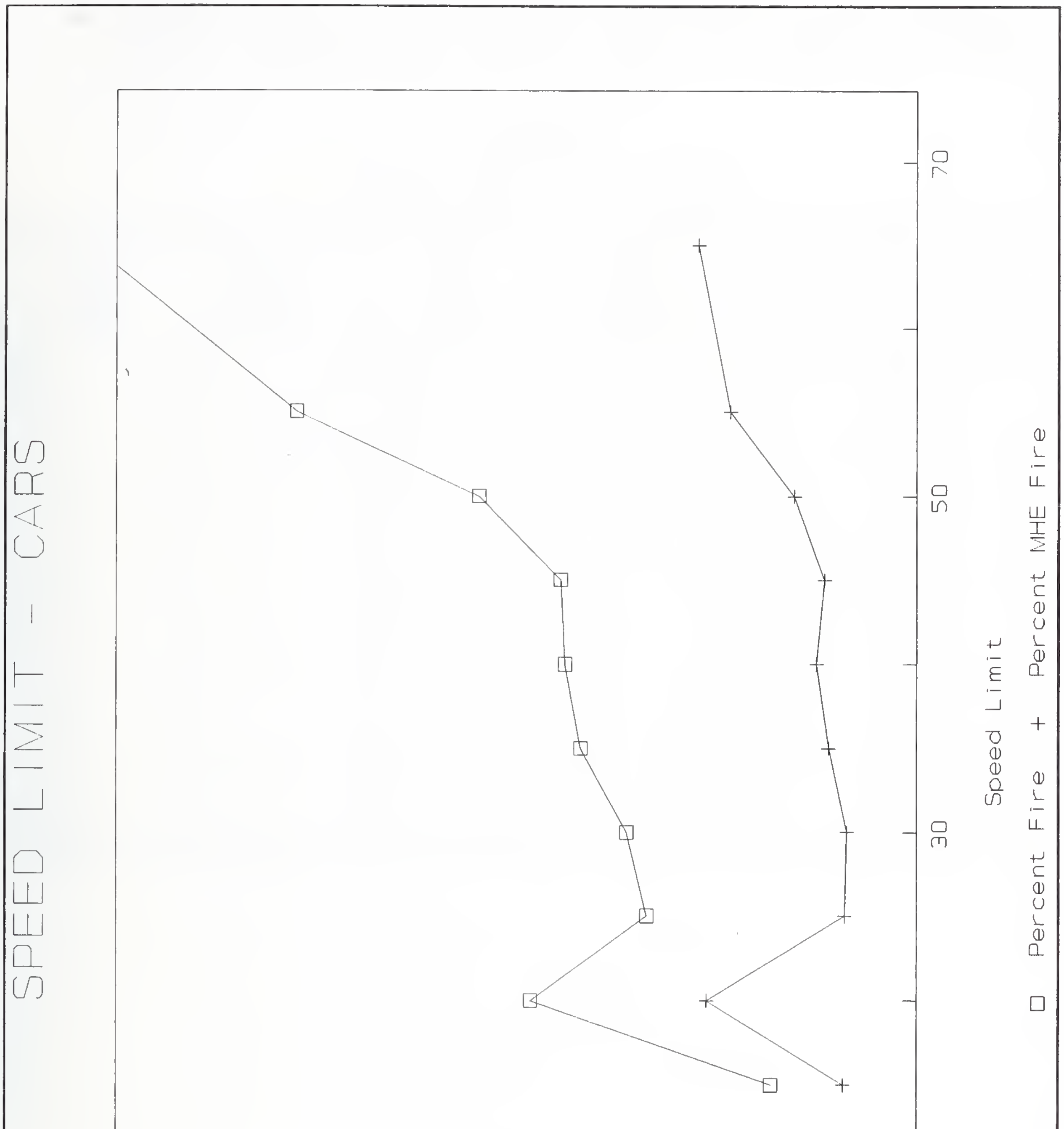

Exhibit 60
SPEED LIMIT - CARS

The exhibits for light trucks suggests that as the speed limit increases the likelihood of a fire/MHE fire for a light truck also rises. The results appear in Exhibits 61 and 62.

Exhibit 61
SPEED LIMIT - LIGHT TRUCKS

Speed Limit MPH	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
15	117	1	0.85	0	0
20	237	4	1.69	3	1.27
25	2683	30	1.12	7	0.26
30	4197	54	1.29	19	0.45
35	7454	92	1.23	25	0.34
40	4956	72	1.45	26	0.52
45	9281	148	1.59	54	0.58
50	4803	103	2.14	30	0.62
55	47711	1618	3.39	558	1.17
65	2672	106	3.97	36	1.34

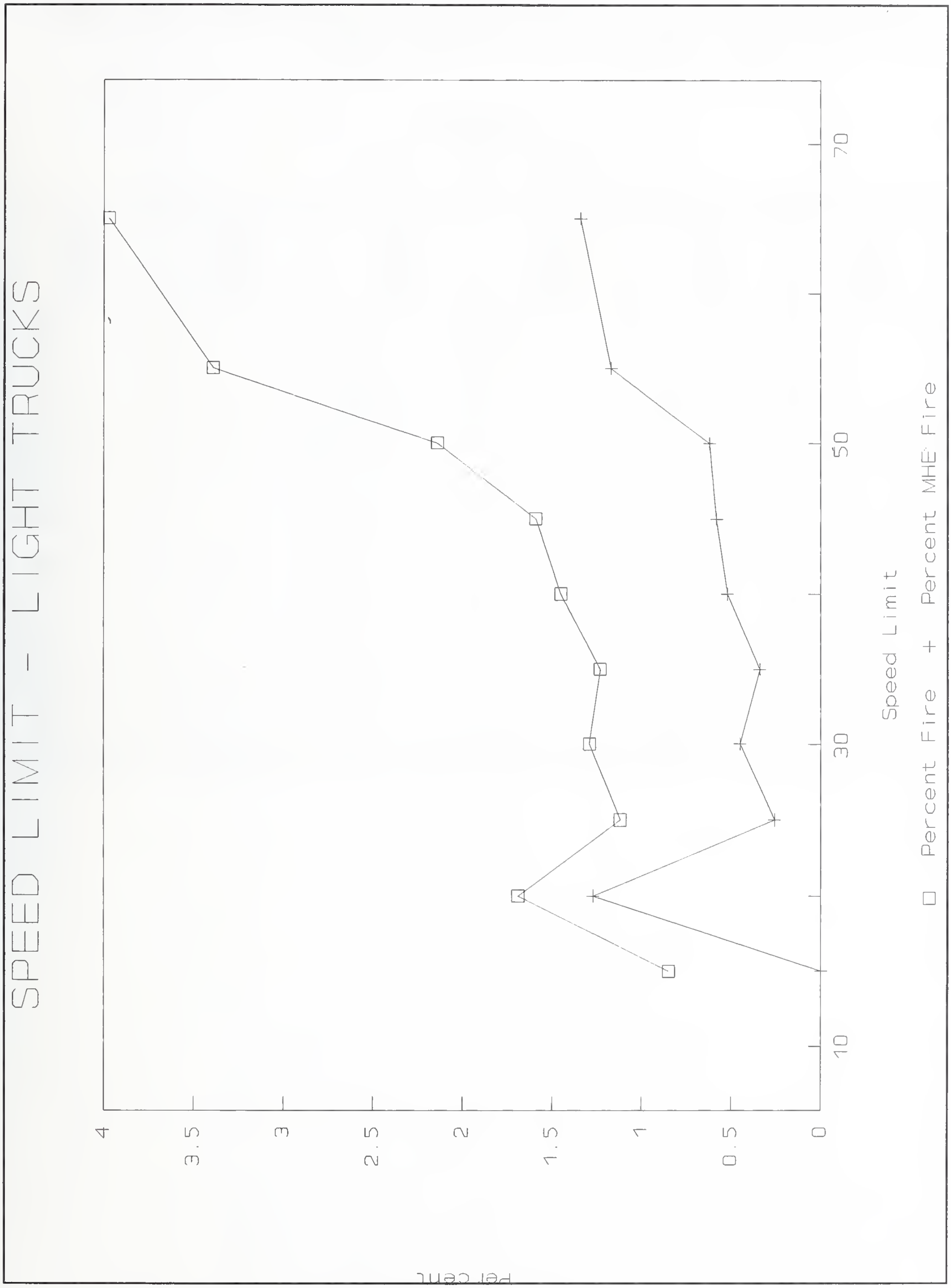

Exhibit 62
SPEED LIMIT - LIGHT TRUCKS

The exhibits for vans suggests that as the speed limit increases the likelihood of a fire/MHE fire for a van also rises. Exhibits 63 and 64 contain the results.

Exhibit 63
SPEED LIMIT - VANS

Speed Limit MPH	Number Fatal Vans	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
15	33	0	0.00	0	0.00
20	29	0	0.00	0	0.00
25	803	6	0.75	1	0.12
35	1686	16	0.95	4	0.24
35	1871	18	0.96	3	0.43
40	1226	21	1.71	6	0.49
35	1814	22	1.21	11	0.61
50	1039	16	1.54	3	0.24
55	7783	214	2.75	60	0.77
65	988	37	3.74	12	1.21

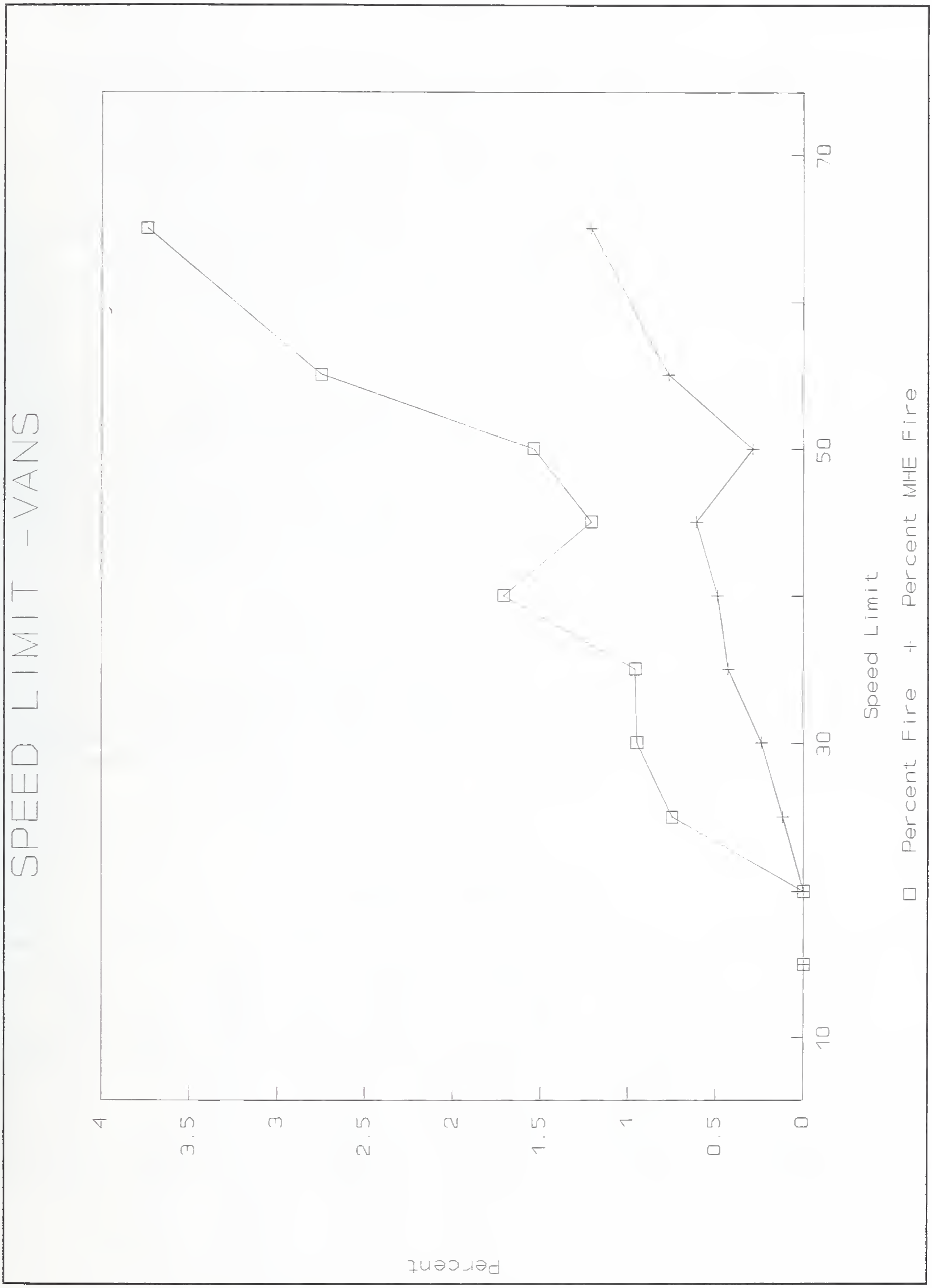

Exhibit 64
SPEED LIMIT - VANS

Salt Effect

The effect of using salt and similar products under conditions of snow and ice may contribute to vehicle corrosion and an increase in the risk of fire/MHE fire. The fifty states and the district of columbia have been partitioned into three groups; salt belt states, sun belt states and other states. The rate of fire and most harmful event fire for the salt belt states is compared to the rates for the sun belt states. The states of Connecticut, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin are considered the "salt belt" states. For purposes of this study the sun belt states are defined to be Alabama, Arizona, Florida, Georgia, Hawaii, Louisiana, Mississippi, New Mexico, South Carolina, and Texas. The remaining states and the District of Columbia are considered the other states.

Vehicles are identified by the state of registration, not the location of the crash. Foreign registered vehicles, unregistered vehicles, U.S. Government registered vehicles, etc., are not counted. Cars registered in a state using large amounts of salt and other corrosive materials on their roadways have approximately a 25 percent higher rate of occurrence of fires than do cars in the sun belt states. However, cars registered in the salt belt states are approximately 40 percent less likely to have a fire identified as the MHE as a car registered in sun belt states. A total of 2676 cars from the salt belt states experienced a fire. There were 1575 crashes involving a car from the sun belt states that had a fire. There were 478 cars from the salt belt states, which were identified as having a fire as the MHE. A total of 609 cars from sun belt states were identified as having a fire as the MHE. See Exhibits 65 and 66 for the results. The decrease in the MHE fire for salt belt states compared to sun belt states was not anticipated. To check the results the analysis was repeated with the additional requirement that the vehicle age would be at least five years old. Vehicles newer than this would likely not show the signs of corrosion. However, the results were approximately the same.

Exhibit 65
SALT EFFECT - CARS

Salt Status	Cars in Fatal Crashes	Number Fire Cars	Percent Fire Cars	Number MHEF Cars	Percent MHEF Cars
Salt Belt	103965	2676	2.57	478	0.46
Sun Belt	77898	1575	2.02	609	0.78
Other	95309	2378	2.50	791	0.83

Exhibit 66
95 PERCENT CONFIDENCE LIMITS FOR SALT EFFECT - CARS

Salt Status	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Salt Belt	2.48	2.57	2.67		0.42	0.46	0.50
Sun Belt	1.92	2.02	2.12		0.72	0.78	0.84
Other	2.40	2.50	2.59		0.77	0.83	0.89

Light trucks registered in a salt belt state have approximately a 10 percent higher rate of occurrence of fires than do light trucks in the sun belt states. However, light trucks registered in the salt belt states are approximately 50 percent less likely to have a fire identified as the MHE than a truck registered in a sun belt state. A total of 558 light trucks from the salt belt states experienced a fire. There were 746 crashes involving a truck from the sun belt states that had a fire. There were 111 light trucks from the salt belt states, which were identified as having a fire as the MHE. A total of 330 light trucks from sun belt states were identified as having a fire as the MHE. The details are in Exhibits 67 and 68.

Exhibit 67
SALT EFFECT - LIGHT TRUCKS

Salt Status	Trucks in Fatal Crashes	Number Fire Trucks	Percent Fire Trucks	Number MHEF Trucks	Percent MHEF Trucks
Salt Belt	19945	558	2.80	111	0.56
Sun Belt	30300	746	2.46	330	1.09
Other	34793	914	2.63	308	0.89

Exhibit 68
95 PERCENT CONFIDENCE LIMITS FOR SALT EFFECT - LIGHT TRUCKS

Salt Status	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Salt Belt	2.57	2.80	3.03		0.45	0.56	0.66
Sun Belt	2.29	2.46	2.64		0.97	1.09	1.21
Other	2.46	2.63	2.80		0.79	0.89	0.98

Vans registered in salt belt states have approximately a 5 percent higher rate of occurrence of

fires than vans registered in sun belt states. Vans registered in salt belt states are about 40 percent less likely to have a MHE fire than a van from the sun belt states. A total of 141 vans from the salt belt states experienced a fire. There were 79 crashes involving a van from the sun belt states that had a fire. There were 29 vans from the salt belt states and sun belt states, which were identified as having a fire as the MHE. Exhibits 69 and 70 contain the results.

Exhibit 69
SALT EFFECT - VANS

Salt Status	Vans in Fatal Crashes	Number Fire Vans	Percent Fire Vans	Number MHEF Vans	Percent MHEF Vans
Salt Belt	7420	141	1.90	29	0.39
Sun Belt	4312	79	1.83	29	0.67
Other	5702	127	2.23	45	0.79

Exhibit 70
95 PERCENT CONFIDENCE LIMITS FOR SALT EFFECT - VANS

Salt Status	Lower Limit	Percent Fire	Upper Limit		Lower Limit	Percent MHEF	Upper Limit
Salt Belt	1.59	1.90	2.21		0.25	0.39	0.53
Sun Belt	1.43	1.83	2.23		0.43	0.67	0.92
Other	1.84	2.23	2.61		0.56	0.79	1.02

Fatality Estimates Due to Fire

The cause of death is often not clear cut. FARS data are used to compute estimates of fatalities due to fire occurrence, and lower and upper bounds of fatalities due to fire. A fatality is counted if the fatality occurred in a model year 1978 or newer car, truck, or van from 1979 to 1992. The apparent increase in the number of fatalities over time may in part be due to the increasing number of 1978 and later model year vehicles, as well as, the general increase in vehicle miles traveled. In addition to the numbers of fatalities, the percentage of total occupant fatalities associated with fire is also presented.

The number of deaths caused by fire was estimated and appears in Exhibit 71. The underlying assumption of Exhibit 71 is that if the most harmful event field is coded as fire, then at least one death in that vehicle was caused by fire. This provides the estimate of the minimum number of fatalities. The most harmful event (MHE) estimate assumes that all deaths within a vehicle coded as a most harmful event fire were due to fire. If the most harmful event field is coded as anything other than fire then at least one individual in the crash died of a cause other than fire, but the other fatalities, if there were more than one

fatality, could have been due to fire. The sum of these additional fatalities are then added to the minimum number of fatalities to obtain the maximum number of fatalities. The fifth column is the total number of fatalities in 1978 or newer cars, trucks, or vans. The last row of the exhibit contains the mean of the last three years 1990 - 1992. The mean of the last

Exhibit 71
FATALITY ESTIMATES DUE TO FIRE BY YEAR OF CRASH

Year of Crash	Minimum Number of Fatalities	MHE Number of Fatalities	Maximum Number of Fatalities	Total Car Truck Van Fatalities
1979	84	117	156	7049
1980	135	186	222	9985
1981	151	200	264	12004
1982	129	179	228	12072
1983	148	199	264	13447
1984	157	197	277	15793
1985	148	178	275	17866
1986	203	272	392	20230
1987	249	317	437	23086
1988	260	355	494	25532
1989	255	336	494	26514
1990	286	348	488	26553
1991	286	376	523	26894
1992	231	297	459	26264
Total	2700	3557	4973	263289
Mean 90-92	261	340	490	26570

three years is less susceptible to any distortion that may be due to the restriction of all vehicle being 1978 and newer models. The results, by the year of the crash, are presented in Exhibit 71.

Exhibit 72 displays columns 2, 3, and 4 divided by column 5 of Exhibit 71 i.e. the estimates of minimum, MHE, and maximum number of fatalities due to fire in each year are presented as a percent of all deaths that year, which occurred in 1978 or later model year cars, trucks or vans. These percentages are not sensitive to the limited number of 1978 or later model

Exhibit 72
PERCENT OF FATALITY ESTIMATES DUE TO FIRE BY YEAR OF CRASH

Year of Crash	Minimum Percent of Fatalities	MHE Percent of Fatalities	Maximum Percent of Fatalities
1979	1.19	1.66	2.21
1980	1.35	1.80	2.22
1981	1.26	1.67	2.20
1982	1.07	1.48	1.84
1983	1.10	1.48	1.96
1984	0.88	1.25	1.75
1985	0.82	1.00	1.89
1986	1.02	1.34	1.94
1987	1.08	1.37	1.89
1988	1.02	1.34	1.84
1989	0.88	1.27	1.83
1990	1.00	1.31	1.84
1991	1.06	1.40	1.94
1992	0.88	1.13	1.75
Mean	1.03	1.35	1.89
Mean 90-92	0.98	1.28	1.84

year vehicles as is Exhibit 71. The data shows a slightly decreasing trend for percentage of deaths for all three measures over time.

Extrication

Extrication has a fundamentally different type of relationship with fire than do the previous variables which have been examined so far. The previous variables are expected to have a "causal" relation with fire. That is a change in the speed limit or object struck would most likely change the rate of vehicle fires. However, although extrication does not cause fires and fires do not cause extrication, the two variables may be associated. Both fire and

extrication may be more prevalent in severe crashes. In addition extrication is performed at the person level not the vehicle level. Note that the fire rate and MHE Fire rate approximately doubles if extrication is involved. The results are found in Exhibit 73.

Exhibit 73
EXTRICATION

Extrication Status	Fire in Vehicle	No Fire	Percent Fire	MHE Fire	MHE Not Fire	Percent MHE Fire
Extricated	2161	43633	4.72	582	45212	1.27
Not extricated	13550	607666	2.18	4107	617109	0.66
Unknown	467	10017	4.45	114	10370	1.09

Statistical Models

An empirical statistical model proves useful to approximate the response (fire/MHE fire) over the limited ranges of available variables. The models separate the effects of the input variables and permit one to examine the net effect of a variable on fires/MHE fires, holding all other variables in the model constant. Many models were estimated to examine the effects on fire/MHE fire for cars, light trucks and vans. Models that contain the statistically significant predictor variables are evaluated for both fire and MHE fire. Overall models include a set of dichotomous variables that account for the differences among vehicle types. In addition, models for each vehicle type were estimated. Although many improvements have been made in vehicle design over the time period of this study, much of this information is not contained in the available data bases and therefore was not considered in this analysis.

The results of the modeling effort are expressed in terms of the odds ratio denoted by the Greek letter psi, Ψ. The odds ratio, Ψ, is the quotient of the odds, i.e., the odds ratio of the odds 10 to 1 is 10/1 = 10.0. The odds ratio of 2 to 5 is 2/5 = 0.4. An odds ratio of 2 means that it (fire/MHE fire) is twice as likely to occur in the presence vs. the absence of the particular characteristic (e.g., rear impact, impact with a narrow object, etc.). The percentage increase/decrease is defined by the equation (odds ratio - 1) * 100. If the odds ratio of an independent variable is 1, then the dependent variable (fire/MHE fire) is not sensitive to changes of the independent variable. The closer an odds ratio is to 1 (using a multiplicative scale; the logarithm of the scale is a conventional metric) the less sensitive the dependent variable is to changes in the independent variable.

To obtain the odds ratio, one exponentiates the estimated model coefficient, denoted by the Greek letter beta, i.e., $\Psi = e^{\beta}$, (i.e., the estimated change in the log of the odds ratio). The probability that β, and thus Ψ, occurred by chance is denoted by p. The requirement for including a variable in the analysis of the base model was that p would be less than 0.05; that is, the probability that β was statistically significantly different from zero, which is equivalent to Ψ being statistically different from 1, was at least 0.95. In order to compare odds ratios across vehicle specific models, if a variable was included in the base model and could be included in the vehicle specific models, it was, even if p was larger than 0.05. The models required the use of some polytomous variables, i.e., more than two states, e.g., vehicle type (cars, light trucks, and vans). The polytomous variables were coded as a set of dichotomous variables. The number of dichotomous variables required to consider all levels is one less than the number of levels of the polytomous variable. For example, vehicle type (cars, light trucks and vans) has three levels. Therefore, two dichotomous variables are needed to represent the polytomous variable vehicle type, where the omitted variable is implicitly included as the "reference group". All relationships for this group of variables are expressed as being relative to the reference group. Thus, if two vehicle type variables are included for light trucks and vans, observed relationships are stated as the odds ratio of fire occurrence for light trucks relative to cars and vans relative to cars, all other things being equal. In the event that one of the dichotomous variables in the set is included in the model, all dichotomous variables for the selected polytomous variable were included.

Base Models for Fire/MHE Fire

Exhibit 74 contains the odds ratio and the p values for the base models for fire and MHE fire.

Exhibit 74
BASE MODEL FOR FIRE AND MHE FIRE

Variable	Odds Ratio Fire Ψ	p Fire	Odds Ratio MHEF Ψ	p MHEF
Vehicle age	1.026	0.0001	N/A	N/A
Model year	N/A	N/A	0.970	0.0001
Vehicle type				
Truck vs. Car	1.075	0.0001	1.351	0.0001
Van vs. Car	0.975	0.2281	1.133	0.2758
Age of driver	0.991	0.0001	0.992	0.0001
Night vs. Day	1.531	0.0001	1.731	0.0001
Speed limit	1.035	0.0001	1.042	0.0001
Multiple-vehicle	0.807	0.0001	0.542	0.0001
Area of damage				
Rollover	N/A	N/A	0.414	0.0001
Rear	2.157	0.0001	1.796	0.0001
Front	1.073	0.0128	0.527	0.0001
Side	0.832	0.0001	0.394	0.0001
Object struck				
Vehicle	4.541	0.0001	5.57	0.0001
Narrow	7.931	0.0001	11.28	0.0001
Fixed	6.217	0.0001	9.122	0.0001
Overturn	1.780	0.0001	2.290	0.0001

Vehicle age is included as a variable when modeling the occurrence of a fire but is not included when modeling MHE fire since it is not statistically significant. For the same reason, model year and rollover are not included when modeling fire but are included when modeling MHE fire. For both fire and MHE fire, the truck vs. car dichotomous variable is

significant and therefore, the van vs. car dichotomous variable should be included.

Interpretation of the Odds Ratios - Base Models

All statements in this section describing the outcome of the statistical models cover only vehicles involved in fatal crashes, unless otherwise noted. The data suggest that as a vehicle ages a fire is a more likely outcome. For each year the vehicle ages, the odds ratio increases by a factor of 1.026. That is, everything else being equal, a vehicle that is ten years older than another is $(1.026^{10} - 1)*100 = 29.3$ percent more likely to have a fire than the newer vehicle. Vehicle age does not seem to affect the occurrence of MHE fire.

Model year was not found to have an appreciable effect on fires; however, model year had a significant effect on MHE fires. For MHE fires, newer model year vehicles are less susceptible to being classified as having fire as the MHE. A difference of ten years in model year produces an odds ratio of $0.970^{10} = 0.74$ for MHE fires. That is if two vehicles differ only by ten model years the older vehicle is $(0.970^{-10} - 1)*100 = 35.1$ percent more likely to have a MHE fire than the newer vehicle.

Fire and MHE fire are both sensitive to the type of vehicle involved. A fatal crash-involved truck is 7.5/35.1 percent more likely than a car to have a fire/MHE fire (ceteris paribus). A van is 2.5 percent less likely than a car to have a fire. However, a van is 13.3 percent more likely than a car to have a fire classified as MHE fire.

Vehicles driven by younger drivers are more likely to experience a fire in a fatal crash or a fire classified as a MHE than are vehicles driven by older drivers. An increase of ten years in driver age lowers the odds ratio to $0.991^{10} = 0.914$ $(0.992^{10} = 0.923)$ for a fire (MHE fire). That is, the rates of fire/MHE fire increase by $(.991^{-10} - 1)*100 = 9.6$ percent and $(.992^{-10} - 1)*100 = 8.3$ percent, respectively, for drivers that are ten years younger.

Vehicles in nighttime fatal crashes have higher rates of fire/MHE fire than vehicles that are involved in fatal crashes during the day. This may be due to the greater proportion of single-vehicle crashes that occur at night, plus the possibility of greater impact speeds associated with the much higher rates of alcohol involvement exhibited by fatal crash-involved drivers during the night. Vehicles involved at night are 53.1 percent/73.1 percent more likely to have a fire/MHE fire than those involved during the day. For this study, night is defined as 6:00 p.m. to 5:59 a.m., and day is from 6:00 a.m. to 5:59 p.m.

Fatal crash-involved vehicles on roadways with higher speed limits are associated with a higher rate of fires and MHE fires than those on roadways with lower speed limits. Each ten mile per hour increase in speed limit raises the odds ratio of a fire/MHE fire by $(1.035^{10} = 1.410)/(1.042^{10} = 1.509)$, respectively. That is, the rate of vehicle fires rises by $(1.035^{10} - 1)*100 = 41.1$ percent/$(1.042^{10} - 1)*100 = 50.9$ percent, respectively for fire/MHE fire. Contrasting vehicles involved in fatal crashes on roads with speed limits of 30 mph to 55 mph (an increase of 25 mph), raises the likelihood of a fire/MHE fire by 136.3 percent/179.7 percent. That is, the odds ratios are 2.363/2.797, respectively.

Vehicles in multiple-vehicle fatal crashes are less likely to have a fire/MHE fire than are vehicles in single-vehicle fatal crashes. Single-vehicle fatal crashes are $(0.807^{-1} - 1)*100 = -23.9$ percent/$(0.542^{-1} - 1)*100 = 84.5$ percent more likely to result in a fire/MHE fire than

are vehicles in multiple-vehicle fatal crashes.

The variable, *Area of damage,* has been partitioned differently for fire and MHE fire. In particular, the cases of rollover have been absorbed in the control set of cases for the output variable fire, but not for the output variables MHE fire. To interpret the results, all values of odds ratio, Ψ, are divided by the odds ratio for being struck in the side to obtain Ψ'. For fire, the values of Ψ' are Rear (2.157/0.832 = 2.593) and Front (1.073/0.832 = 1.290). For MHE fire, the new values of Ψ' are Rear (1.796/0.394 = 4.558), Front (0.527/0.394 = 1.338) and Rollover (0.414/0.394 = 1.051).

The interpretation for vehicles involved in fatal crashes follows. Vehicles struck in the rear are 159.3 percent/355.8 percent more likely to have a fire/MHE fire than a vehicle struck in the side. Vehicles struck in the front are 29.0 percent/33.8 percent more likely to have a fire/MHE fire than a vehicle struck in the side. There are far more crashes where the damage to the vehicle occurs in the front rather than the rear. Consequently, there are more fires/MHE fires in crashes where the damage to the vehicle occurs in the front rather than the rear (see the Area of Damage exhibits for cars, light trucks and vans, exhibits 30 through 39). Vehicles that rolled over are 5.1 percent more likely to have an MHE fire than a vehicle struck in the side.

Object struck is treated in a similar way. In this case, the odds ratios, Ψ, for Vehicle, Narrow and Fixed are divided by the odds ratio for overturn. The rescaled odds ratios, Ψ', for fire are Vehicle (4.541/1.780 = 2.551), Narrow (7.931/1.780 = 4.456), and Fixed (6.217/1.780 = 3.493). The rescaled odds ratios, Ψ', for MHE fire are Vehicle (5.570/2.290 = 2.432), Narrow (11.280/2.290 = 4.926), and Fixed (9.122/2.290 = 3.983).

Vehicles that struck another vehicle in a fatal crash are 155.1 percent/143.2 percent more likely to have a fire/MHE fire than are overturned vehicles. Vehicles that struck a narrow object, such as a pole, are 345.6 percent/392.6 percent more likely to have a fire/MHE fire than overturned vehicles. Vehicles that struck a fixed object, such as a wall, are 249.3 percent/ 298.3 percent more likely to have a fire/MHE fire than are overturned vehicles.

Vehicle-Specific Models

In addition to the base model, Exhibit 74, models for the variable fire, for each vehicle type (cars, light trucks and vans) were estimated. The sets of odds ratios for each model are in Exhibit 75.

Exhibit 75
BASE MODEL COMPARED TO VEHICLE SPECIFIC MODELS - FIRE
Odds Ratios

Variable	Base Model Ψ	Cars Only Ψ	Cars & Weight Ψ	Trucks Only Ψ	Vans Only Ψ
Vehicle age	1.026	1.031	1.033	1.010	1.006
Vehicle type					
Truck vs. Car	1.075	Cars	Cars &	Trucks	Vans
Van vs. Car	0.975	Only	Weight	Only	Only
Age of driver	0.991	0.991	0.991	0.992	0.993
Night vs. Day	1.531	1.589	1.594	1.396	1.377
Speed limit	1.035	1.032	1.032	1.050	1.050
Multiple-vehicle	0.807	0.773	0.783	0.973	0.979
Car weight in lbs.	N/A	N/A	1.000026	N/A	N/A
Area of damage					
Rear	2.157	2.484	2.482	0.936	0.842
Front	1.073	1.043	1.033	1.175	1.165
Side	0.832	0.790	0.787	1.050	1.074
Object struck					
Vehicle	4.541	4.946	4.952	3.558	3.455
Narrow	7.931	8.024	8.069	7.747	7.451
Fixed	6.217	6.661	6.764	5.116	5.072
Overturn	1.780	2.116	2.144	1.206	1.231

Within the Fatal Accident Reporting System (FARS) data on the weight of a car is collected. These data are generally not available for light trucks and vans. The third column, headed Cars & Weight, are the odds ratios for a model that contains the car weight as an additional independent variable. The weight variable is virtually orthogonal to the vector space spanned by the other variables and therefore there are only small changes between the sets of odds ratios of the cars only model and the cars & weight model. An odds ratio of 1.000026 is the change in the odds ratio for one additional pound of weight of a car. This means that the odds ratio increases to $(1.000026)^{1000} = 1.026$ if the weight of a car is increased by 1000 pounds. That is, ceteris paribus, for every additional 1000 pounds of weight, a car is 2.6 percent more likely to have a fire in a fatal crash. Although the odds ratio is very close to one (due to the scale of the weight variable) it is significantly different from 1 at the $\alpha = 0.0001$ level.

Exhibit 76
BASE MODEL FIRE ODDS RATIO WITH
LOWER AND UPPER 95 PERCENT CONFIDENCE LIMITS[2]

Variable	Lower 95% Limit	Odds Ratio Ψ	Upper 95% Limit
Vehicle age	1.019	1.026	1.6[illegible]2
Vehicle type			
Truck vs. Car	1.021	1.075	1.132
Van vs. Car	0.321	0.975	2.962
Age of driver	0.990	0.991	0.993
Night vs. Day	1.464	1.531	1.602
Speed limit	1.033	1.035	1.038
Multiple-vehicle	0.723	0.807	0.902
Area of damage			
Rear	1.468	2.157	2.364
Front	1.015	1.073	1.134
Side	0.775	0.832	0.894
Object struck			
Vehicle	3.907	4.541	5.278
Narrow	7.007	7.931	8.977
Fixed	5.494	6.217	7.036
Overturn	1.515	1.78	2.092

When comparing cars, light trucks, and vans, i.e., the second, fourth and fifth columns of Exhibit 75, one may compare a variable (row) at a time. As a rough approximation, to determine if the coefficients are significantly different from those of the base model, the upper and lower 95 percent confidence limits, for the variable fire, were calculated. The results of these calculations are in Exhibit 76.

In general, if an estimated odds ratio for a comparison model is within the 95 percent confidence level then one can conclude that there is no measurable difference in the coefficients (although to be certain, the complete statistical test, incorporating the standard

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[2] Hosmer, David W. and Lemeshow, Stanley, Applied Logistic Regression, New York: John Wiley & Sons, Inc., 1989, Chapter 3 p. 44.

errors of both estimates should be computed).

Age of Driver is the only variable that stays within the 95 percent confidence levels when the vehicle types are examined. The second order interactions of vehicle type can be used to account for the differences due to differences among cars, light trucks, and vans. Another approach is used here, namely a model is built for each of the individual vehicle types. This approach, however, does not address the remaining second order interactions. Exhibit 75, Base Model Compared to Vehicle Specific Models - Fire, shows that there are many differences among cars, light trucks, and vans. Perhaps the most important difference, due to vehicle type, is that fires in cars are very susceptible to a crash involving the rear of the car, but this is not so for light trucks or vans. A detail commentary for the variables follows.

To examine the effect of vehicle age across vehicle type note that cars, with an odds ratio of $\Psi = 1.031$, are the most sensitive to the age of the vehicle. Light trucks, with an odds ratio of $\Psi = 1.010$, are less sensitive to vehicle age than are cars, and vans, with an odds ratio of $\Psi = 1.006$, are the least sensitive to vehicle age. For vehicles involved in fatal crashes, a ten-year difference in the age of a car vs. a ten-year difference in the age of a van raises the relative rate of a fire in a car vs. a fire in a van by $\{[(1.031/1.006)^{10} = 1.278] -1\}*100 =$ 27.8 percent. A ten-year difference in the age of a car vs. a ten-year difference in the age of a light truck raises the relative rate of a fire in a car vs. a fire in a truck by $\{[(1.031/1.010)^{10} = 1.228] -1\}*100 = 22.8$ percent.

The effect of the time of day, night vs. day, is not uniform across vehicle types. Note that cars, with an odds ratio of $\Psi = 1.589$, are the most sensitive to the time of day. Light trucks, with an odds ratio of $\Psi = 1.396$, are less sensitive and vans, with an odds ratio of $\Psi = 1.377$, are the least sensitive. The relative rate of fire in a car at night vs. a van at night is $\{[1.589/1.377 = 1.154] -1\}*100 = 15.4$ percent higher.

The speed limit has different effects on the odds ratio across vehicle types. Note that cars, with an odds ratio of 1.032 per mph, are the least sensitive to changes in the posted speed limit. Light trucks and vans, with an odds ratio of 1.050 per mph, are more sensitive to changes in the speed limit. A ten mph difference in the speed limit for a light truck or van vs. a ten mph difference in speed limit for car raises the relative rate of a fire in a light truck or van vs. a fire in a car by $\{[(1.050/1.032/)^{10} = 1.189] - 1\}*100 = 18.9$ percent.

Single-vehicle crashes vs. multiple-vehicle crashes affect vehicle types in slightly different ways. Cars, with an odds ratio of $\Psi = 0.773$, are the most sensitive to multiple-vehicle crashes. Light trucks, with an odds ratio of $\Psi = 0.976$, are less sensitive and vans, with an odds ratio of $\Psi = 0.979$, are the least sensitive. A crash of a car involving no other vehicle vs. a crash of a van involving no other vehicle is 21.0 percent $[\{(0.773/0.979) = 0.790] - 1\}*100]$ less likely to have a fire than a multiple-vehicle car crash vs. a multiple-vehicle van crash. A crash of a truck involving no other vehicle vs. a crash of a car involving no other vehicle is 25.8 percent $[\{(0.973/0.773) = 1.258] -1\}*100]$ more likely to have a fire than a multiple-vehicle truck crash vs. a multiple-vehicle car crash.

The area of damage, i.e., the location of damage (rear, front, or side) seems to produce different rates of fire across vehicle types. Cars, with an odds ratio of $\Psi = 2.484$ for damage to the rear, are more sensitive than light trucks $\Psi = 0.936$, and vans $\Psi = 0.842$ for

damage to the rear. A car with damage to the rear in a fatal crash is {[2.484/0.842 = 3.950] -1}*100 = 395.0 percent more likely to have a fire than a van with damage to the rear in a fatal crash.

Cars, with an odds ratio of Ψ = 1.043, for damage to the front, are less sensitive than light trucks Ψ = 1.175, and vans Ψ = 1.165 for damage to the front. A van receiving frontal damage in a fatal crash is {[1.165/1.043 = 0.895] -1}*100 = 11.7 percent more likely to have a fire than a frontally damaged car. A frontally damaged truck in a fatal crash is {[1.175/1.043 = 1.127] -1}*100 = 12.6 percent more likely to have a fire than a frontally damaged car.

Cars, with an odds ratio of Ψ = 0.790 for damage to the side, are less sensitive than light trucks Ψ = 1.050, and vans Ψ = 1.074 for damage to the side. A side-damaged van in a fatal crash is {[1.074/0.790 = 1.359] -1}*100 = 35.9 percent more likely to have a fire than a side-damaged car. A truck with damage to the side, which is involved in a fatal crash is {[1.050/0.790 = 1.329] -1}*100 = 32.9 percent more likely to have a fire than a car, with damage to the side, which is involved in a fatal crash.

To examine the effect of the type of object struck, on dependent variable fire, the objects have been partitioned into five categories: vehicle, narrow, fixed, overturn and other, across vehicle types. Note that cars, with an odds ratio of Ψ = 4.946 for striking a vehicle, are more sensitive than light trucks Ψ = 3.558, or vans Ψ = 3.455 for striking a vehicle. A car that struck a vehicle in a fatal crash is {[4.946/3.455 = 1.432] -1}*100 = 43.2 percent more likely to have a fire than a van, which struck another vehicle. A car that struck another vehicle in a fatal crash is {[4.946/3.558 = 1.390] -1}*100 = 39.0 percent more likely to have a fire than a truck that struck a vehicle.

Cars, with an odds ratio of Ψ = 8.024 for striking a narrow object such as a telephone pole, are more sensitive than light trucks Ψ = 7.747, and vans Ψ = 7.451 for striking a narrow object. A car that struck a narrow object in a fatal crash is {[8.024/7.451 = 1.077] -1}*100 = 7.7 percent more likely to have a fire than a van that struck a narrow object. A car that struck a narrow object in a fatal crash is {[8.024/7.747 = 1.036] -1}*100 = 3.6 percent more likely to have a fire than a truck, which struck a narrow object, which is involved in a fatal crash.

Cars, with an odds ratio of Ψ = 6.661 for striking a fixed object such as a wall, are more sensitive than light trucks Ψ = 5.116, and vans Ψ = 5.072 that struck a fixed object. A car that struck a fixed object in a fatal crash is {[6.661/5.072 = 1.313] -1}*100 = 31.3 percent more likely to have a fire than a van that struck a fixed object. A car that struck a fixed object in a fatal crash is {[6.661/5.116 = 1.302] -1}*100 = 30.2 percent more likely to have a fire than a truck that struck a fixed object.

Exhibit 77
BASE MODEL COMPARED TO VEHICLE SPECIFIC MODELS - MHE FIRE
Odds Ratios

Variable	Base Model Ψ	Cars Only Ψ	Cars & Weight Ψ	Trucks Only Ψ	Vans Only Ψ
Model year	0.970	0.971	0.970	0.972	0.948
Vehicle type					
Truck vs. Car	1.351	Cars	Cars &	Trucks	Vans
Van vs. Car	1.133	Only	Weight	Only	Only
Age of driver	0.922	0.992	0.991	0.994	1.001
Night vs. Day	1.731	1.787	1.793	1.659	1.297
Speed limit	1.042	1.038	1.038	1.055	1.045
Multiple-vehicle	0.542	0.521	0.521	0.651	0.586
Car weight in lbs.	N/A	N/A	1.000017	N/A	N/A
Area of damage					
Rollover	0.414	0.419	0.432	0.399	0.740
Rear	1.796	2.068	2.116	0.588	1.432
Front	0.527	0.471	0.476	0.676	0.936
Side	0.394	0.339	0.344	0.624	0.912
Object struck					
Vehicle	5.570	5.964	5.977	5.061	2.565
Narrow	11.28	10.207	10.368	14.249	12.890
Fixed	9.122	9.047	9.243	9.651	6.071
Overturn	2.290	2.570	2.535	2.097	0.957

In addition to the base model, Exhibit 74, models for the variable most harmful event fire, for each vehicle type; cars, light trucks and vans were constructed. The sets of odds ratios for each model are in Exhibit 77.

Within the Fatal Accident Reporting System (FARS) data on the weight of a car is collected. These data are generally not available for light trucks and vans. The third column, headed Cars & Weight, are the odds ratios for a model that contains the car weight as an additional independent variable. The weight variable is virtually orthogonal to the vector space spanned by the other variables and therefore there are small changes between the sets of odds ratios

Exhibit 78
BASE MODEL MHE FIRE ODDS RATIO WITH
LOWER AND UPPER 95 PERCENT CONFIDENCE LIMITS

Variable	Lower 95% Limit	Odds Ratio Ψ	Upper 95% Limit
Model Year	0.960	0.970	0.812
Vehicle type			
Truck vs. Car	1.237	1.351	1.476
Van vs. Car	0.925	1.133	1.387
Age of driver	0.990	0.992	0.995
Night vs. Day	1.591	1.731	1.883
Speed limit	1.037	1.042	1.047
Multiple-vehicle	0.445	0.542	0.658
Area of damage			
Rollover	0.343	0.414	0.498
Rear	1.466	1.796	2.201
Front	0.444	0.527	0.625
Side	0.325	0.393	0.477
Object struck			
Vehicle	4.216	5.570	7.359
Narrow	8.981	11.28	14.169
Fixed	7.246	9.122	11.485
Overturn	1.688	2.290	3.107

of the cars only model and the cars & weight model. The reported odds ratio of 1.000017 is the change in the odds ratio for one additional pound of weight of a car. This means that the odds ratio increases to $(1.000017)^{1000} = 1.017$ if the weight of a car is increased by 1000 pounds. That is, for every additional 1000 pounds of weight, a car is 1.7 percent more likely to have a MHE fire, if that car is involved in a fatal crash. However, the odds ratio is very close to one and is NOT significantly different from 1 at the $\alpha = 0.1$ level, i.e., 10 percent confidence level.

When comparing cars, light trucks, and vans, i.e., the second, fourth and fifth columns of Exhibit 77, one may compare a variable (row) at a time. As a rough approximation, to determine if the coefficients are significantly different from those of the base model, the upper and lower 95 percent confidence limits, for the variable most harmful event fire, were

calculated. The results of these calculations are in Exhibit 78. In general, if an estimated odds ratio for a comparison model is within the 95 percent confidence level then one can conclude that there is no measurable difference in the coefficients (although to be certain, the complete statistical test, incorporating the standard errors of both estimates should be computed).

None of the variables stay within the 95 percent confidence levels when the individual vehicle types are examined. The vehicle type second-order interactions can be used to account for the differences in the coefficients. Another approach is used here, namely a model is built for each of the individual vehicle types. This approach, however, does not address the remaining second order interactions. Exhibit 77, Base Model Compared to Vehicle Specific Models, MHE Fire shows that there are many differences among cars, light trucks, and vans. Perhaps the most important difference, due to vehicle type, is that MHE fires in cars are very susceptible to a crash involving the rear of the car, but this is not the case for light trucks or vans.

To examine the effect of model year of the vehicle across vehicle type note that cars, with an odds ratio of $\Psi = 0.971$, are the less sensitive to the model year than light trucks with an odds ratio of $\Psi = 0.972$ but are more sensitive to model year than vans, with an odds ratio of $\Psi = 0.948$. A ten-year difference in the model year of a car vs. a ten-year difference in the model year of a van raises the likelihood of a MHE fire in a car vs. a MHE fire in a van by $\{[(0.971/0.948)^{10} = 1.270] -1\}*100 = 27.0$ percent. A ten-year difference in the model year of a truck vs. a ten-year difference in the model year of a car raises the likelihood of a MHE fire in a truck vs. a MHE fire in a car by $\{[(0.972/0.971)^{10} = 1.010] -1\}*100 = 1.0$ percent.

The age of the driver has different effects on the MHE fire across vehicle types. The age of the driver odds ratio is 0.992/0.994 for cars/light trucks respectively. This suggests that the age of the driver of a car has a slightly greater effect on the likelihood of a crash resulting in a MHE fire. Younger drivers are more likely to have a crash resulting in a MHE fire than older drivers, and the effect is greater with cars than with light trucks. However, there is no real statistical difference between the two numbers. The odds ratio of driver age for vans is 1.001. This value is not statistically different from 1. Therefore one may conclude that the age of a driver does not effect the rate of occurrence of MHE fire of vans.

The effect of the time of day, night vs. day, is not uniform across vehicle types for MHE fire. Note that cars, with an odds ratio of $\Psi = 1.787$, are the most sensitive to the time of day. Light trucks, with an odds ratio of $\Psi = 1.659$, are less sensitive and vans, with an odds ratio of $\Psi = 1.297$, are the least sensitive. The relative rate of fire in a car at night vs. a van at night is $\{[1.787/1.297 = 1.548] -1\}*100 = 54.8$ percent higher.

The speed limit has different effects on the odds ratio across vehicle types. Note that cars, with an odds ratio of 1.038 per mph, are the least sensitive to changes of the speed limit. Light trucks/vans, with odds ratios of 1.055/1.045 per mph respectively, are more sensitive to changes in the speed limit. A ten mph difference in the speed limit for a truck vs. a ten mph difference in speed limit for a car raises the relative rate of a MHE fire in a truck vs. a MHE fire in a car by $\{[(1.055/1.038)^{10} = 1.176] - 1\}*100 = 17.6$ percent.

Single-vehicle crashes vs. multiple-vehicle crashes affects the rate of occurrence of MHE fire

of different vehicle types in slightly different ways. Cars, with an odds ratio of $\Psi = 0.521$, are the most sensitive to the number of vehicles involved in the crash. Light trucks, with an odds ratio of $\Psi = 0.651$, are least sensitive and vans, with an odds ratio of $\Psi = 0.589$, are between cars and light trucks. A crash of a van involving no other vehicle vs. a crash of a car involving no other vehicle is 12.4 percent [{(0.586/0.521) = 1.124] -1}*100] more likely to have a MHE fire than a multiple-vehicle van crash vs. a multiple-vehicle car crash. A crash of a truck involving no other vehicle vs. a crash of a car involving no other vehicle is 24.9 percent [{(0.651/0.521) = 1.249 -1}*100] more likely to have a MHE fire than a multiple-vehicle truck crash vs. a multiple-vehicle car crash.

The area of damage, i.e., the location of damage (rear, front, or side) seems to produce different rates of MHE fire across vehicle types. Cars, with an odds ratio of $\Psi = 2.068$ for damage to the rear, are more sensitive than light trucks $\Psi = 0.588$, and vans $\Psi = 1.432$ for damage to the rear. A car with damage to the rear in a fatal crash is 44.4 percent, [{(2.068/1.432) = 1.444 -1}*100], more likely to have a MHE fire than a van with damage to the rear in a fatal crash. A car with damage to the rear in a fatal crash is 251.7 percent [{(2.068/0.588) = 3.517 -1}*100] more likely to have a MHE fire than a truck with damage to the rear in a fatal crash.

Cars, with an odds ratio of $\Psi = 0.471$, for damage to the front, are relatively less likely to have a MHE fire than light trucks with an odds ratio of $\Psi = 0.676$, or vans with an odds ratio of $\Psi = 0.936$ for damage to the front. A van receiving frontal damage in a fatal crash is 98.7 percent [{(0.936/0.471) = 1.987 -1}*100] more likely to have a MHE fire than a frontally damaged car. A frontally damaged truck in a fatal crash is 86.1 percent [{(0.936/0.471) = 1.861 -1}*100] more likely to have a MHE fire than a frontally damaged car.

Cars, with an odds ratio of $\Psi = 0.339$ for damage to the side, are relatively less likely to have a MHE fire than light trucks with an odds ratio of $\Psi = 0.624$, or vans with an odds ratio of $\Psi = 0.912$ for damage to the side. A side-damaged van in a fatal crash is 46.2 percent [{(0.912/0.624) = 1.462 -1}*100] more likely to have a MHE fire than a side-damaged car. A truck with damage to the side, which is involved in a fatal crash is 84.1 percent [{(0.624/0.339) = 1.841 -1}*100] more likely to have a MHE fire than a car, with damage to the side, which is involved in a fatal crash.

To examine the effect of the type of object struck on MHE fire, the objects have been partitioned into categories; vehicle, narrow, fixed, and overturn; across vehicle types. Note that cars, with an odds ratio of $\Psi = 5.964$ are more likely to have a MHE fire following striking a vehicle, than light trucks with an odds ratio of $\Psi = 5.061$, or vans with an odds ratio of $\Psi = 2.565$. A car that struck a vehicle in a fatal crash is 132.5 percent [{(5.964/2.565) = 2.325 -1}*100] more likely to have a MHE fire than a van, which struck another vehicle. A car that struck another vehicle in a fatal crash is 17.8 percent [{(5.964/5.061) = 1.178 -1}*100] more likely to have a MHE fire than a truck that struck a vehicle.

Cars, with an odds ratio of $\Psi = 10.207$ are relatively less likely to have a MHE fire if they strike a narrow object such as a telephone pole than light trucks with an odds ratio of $\Psi = 14.249$, or vans with an odds ratio of $\Psi = 12.890$. A van that struck a narrow object in a fatal crash is 26.3 percent [{(12.890/10.207/) = 1.263] -1}*100] more likely to have a MHE

fire than a car that struck a narrow object. A truck that struck a narrow object in a fatal crash is 39.6 percent {[14.249/10.207 = 1.396] -1}*100 more likely to have a MHE fire than a car, which struck a narrow object, which is involved in a fatal crash.

Cars, with an odds ratio of Ψ = 9.047 for striking a fixed object such as a wall, are relatively less likely to have a MHE fire than light trucks with an odds ratio of Ψ = 9.651 but relatively more likely to have a MHE fire than vans with an odds ratio of Ψ = 6.071. A car that struck a fixed object in a fatal crash is 49.0 percent [{(9.047/6.071) = 1.490 - 1}*100] = more likely to have a MHE fire than a van that struck a fixed object. A truck that struck a fixed object in a fatal crash is 6.7 percent [{(9.651/9.047) = 1.067] -1}*100] more likely to have a MHE fire than a car that struck a fixed object.

Many variables used in the model analysis are included so that the effects of these variables can be removed and will not distort the actual findings of this investigation. The drivers age, the time of day of the crash, and the number of vehicles involved in the crash are examples of variables that have an effect on the probability of having a fire/MHE fire in a fatal crash. Some variables used in the modeling cannot be accounted for in any type of compliance test.

Fuel Tank Location

The fuel tank location was partitioned into two levels; in front of the rear axle and behind the rear axle. A model to estimate the probability of the occurrence of fire was developed using two input variables, fuel tank location and speed limit. The data for this model was limited to rear end crashes only and therefore the odds ratio for speed limit can not be compared to other data in this study. The odds ratios, 95 percent confidence limits and the value of p for the two variables are given in Exhibit 79. The model estimates that placing the tank forward of the rear axle reduces the probability of a fire by [(1 - 0.705)*100] = 29.5 percent.

Exhibit 79
SPECIAL MODEL OF FUEL TANK LOCATION EFFECT FOR REAR IMPACT FIRES

Variable	Lower 95% Limit	Odds Ratio Fire Ψ	Upper 95% Limit	p Fire
Forward Tank	0.537	0.705	0.925	0.0120
Speed Limit	1.007	1.021	1.035	0.0040

Michigan Data

Michigan collects data on fuel leaks and fires as part of their police accident reporting system. These data are collected for any injury, including fatalities, and property damage crashes. Michigan has partitioned the exposure data into four disjoint categories, namely: (1) fuel leak but no fire, (2) fire but no fuel leak, (3) fuel leak and fire, and (4) no fuel leak and no fire. The Michigan area of impact, (similar to the area of damage) was partitioned into four disjoint categories: front, rear, side and other. Data were examined for the years 1982 to 1991 for 1978 and newer model year vehicles. In addition to the different time frame over which the Michigan data were collected, there are two other distinct differences between the Michigan data and the FARS data used in the previous sections of this report. First the Michigan police crashes reports, on which this part of the analysis is based, collects information on fuel leaks. Second the Michigan data contains information on all crashes for which a police accident report was filed and is not limited to fatal crashes as is FARS.

The FARS data produce rates of fire and MHE fire considerably higher (about double) for cars with damage to the rear than to the front of the car. However, the Michigan data for both injuries including fatalities (Exhibits 80, 81, and 82) and property damage only crashes for cars (Exhibits 83, 84, and 85) do not support this finding. In fact the rate of occurrence of fire but no leak for crashes involving personal injury including death, is 0.28 percent when the impact area is the front compared to 0.10 for impact area to the rear. This difference may be due to the fact that a much larger percentage of less serious, i.e. not fatal, crashes are included. See the exhibit of Michigan fatalities within cars later in this section, Exhibit 101.

Vehicles in crashes resulting an injury; incapacitating, non-incapacitating or possible, are more likely to have a fire, with or without a leak, than a crash where only property is damaged, see Exhibit 81 and 84. That is, more serious crashes are more likely to have a fire than less serious crashes.

Point of Impact

Exhibit 80
MICHIGAN FREQUENCY POINT OF IMPACT
INJURIES INCLUDING FATALITIES - CARS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	3687	1033	286	360749
Rear	1966	163	98	168952
Side	1170	170	72	99982
Other	1317	153	56	46208

Exhibit 81
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
INJURIES INCLUDING FATALITIES - CARS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	1.01	0.28	0.08	98.63
Rear	1.15	0.10	0.06	98.70
Side	1.15	0.17	0.07	98.61
Other	2.76	0.32	0.12	96.80

The column headings for Exhibits 82, 85, 88, 91, 94, 97, and 100 mean the following: "Low Lim" and "Up Lim" refer to the lower and upper 95 percent confidence limits for the variable between. "% Leak" refers to the percentage of crash-involved vehicles that had a fuel leak but no fire. "% Fire" refers to the percentage of vehicles that had a fire but no fuel leak. "Fire Leak" refers to the percentage of vehicles that had both a fire and a fuel leak.

Exhibit 82
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
INJURIES INCLUDING FATALITIES - CARS

Impact Area	Lo Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.98	1.01	1.04		0.27	0.28	0.30		0.07	0.08	0.09
Rear	1.10	1.15	1.20		0.08	0.10	0.11		0.05	0.06	0.07
Side	1.09	1.15	1.22		0.14	0.17	0.19		0.05	0.07	0.09
Other	2.61	2.76	2.91		0.27	0.32	0.37		0.09	0.12	0.15

Exhibit 83
MICHIGAN FREQUENCY POINT OF IMPACT
PROPERTY DAMAGE ONLY - CARS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	2715	1341	335	1573796
Rear	1559	491	129	678976
Side	541	261	66	383066
Other	1066	1256	114	78871

Exhibit 84
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
PROPERTY DAMAGE ONLY - CARS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	0.17	0.08	0.02	99.72
Rear	0.23	0.07	0.02	99.68
Side	0.14	0.07	0.02	99.77
Other	1.31	1.54	0.14	97.00

Exhibit 85
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
PROPERTY DAMAGE ONLY - CARS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.17	0.17	0.18		0.08	0.08	0.08		0.02	0.02	0.02
Rear	0.22	0.23	0.24		0.07	0.07	0.08		0.02	0.02	0.02
Side	0.13	0.14	0.15		0.06	0.07	0.08		0.01	0.02	0.02
Other	1.23	1.31	1.39		1.46	1.54	1.63		0.11	0.14	0.17

The data of the last six exhibits can be combined to provide estimates of fires for both personal injury and property damage only crashes. When this is done one can report on the

numbers and percentage rates of fire for the sum of personal injuries and property damage crashes which make up the police reported crashes. Combining the data results in estimates of rate of fires that are bounded above and below by the two sets of data, that is the results will be between the other two estimates. In addition, since the crashes have been pooled, the confidence intervals will be tighter. The results are found in Exhibits 86, 87 and 88. The combined data, however, does not provide any information on fires with respect to the severity of the crash. Usually crashes that produced personal injury were more severe than crashes that did not and have a higher fire rate. The results show that there were a total of 6024 cars that had either a fire or a fire and a fuel leak out of 3,410,645 reported crashes. This results in an overall fire rate of 0.18 percent.

Exhibit 86
MICHIGAN FREQUENCY POINT OF IMPACT
ALL REPORTED CRASHES - CARS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	6402	2374	621	1934545
Rear	3525	654	227	847928
Side	1711	431	138	483048
Other	2383	1409	170	125079

Exhibit 87
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
ALL REPORTED CRASHES - CARS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	0.33	0.12	0.03	99.52
Rear	0.41	0.09	0.03	99.48
Side	0.35	0.09	0.03	99.53
Other	1.85	1.09	0.13	96.93

Exhibit 88
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
ALL REPORTED CRASHES - CARS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.32	0.33	0.34		0.12	0.12	0.13		0.03	0.03	0.03
Rear	0.40	0.41	0.43		0.07	0.08	0.08		0.02	0.03	0.03
Side	0.34	0.35	0.37		0.08	0.09	0.10		0.02	0.03	0.03
Other	1.77	1.85	1.92		1.04	1.09	1.15		0.11	0.13	0.15

Crash-involved light trucks involving personal injury, with damage to the rear, have fewer fires and a lower rate of fire than any other impact area (Exhibits 89 and 90). This is consistent with the FARS data, Exhibit 36.

Exhibit 89
MICHIGAN FREQUENCY POINT OF IMPACT
INJURIES INCLUDING FATALITIES - LIGHT TRUCKS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	692	159	66	42659
Rear	191	19	7	17640
Side	275	17	10	10268
Other	547	35	15	13059

Exhibit 90

MICHIGAN PERCENTAGE RATE POINT OF IMPACT

INJURIES INCLUDING FATALITIES - LIGHT TRUCKS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	1.59	0.36	0.15	97.90
Rear	1.07	0.11	0.04	98.78
Side	2.60	0.16	0.04	97.14
Other	4.19	0.26	0.11	95.44

Exhibit 91

95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE

by POINT OF IMPACT

INJURIES INCLUDING FATALITIES - LIGHT TRUCKS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Leak Fire	Up Lim
Front	1.47	1.59	1.71		0.31	0.36	0.42		0.11	0.15	0.19
Rear	0.92	1.07	1.22		0.06	0.11	0.15		0.01	0.04	0.07
Side	2.3	2.60	2.91		0.08	0.16	0.24		0.04	0.09	0.15
Other	3.86	4.19	4.53		0.17	0.26	0.34		0.05	0.11	0.17

Exhibit 92

MICHIGAN FREQUENCY POINT OF IMPACT

PROPERTY DAMAGE ONLY - LIGHT TRUCKS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	496	190	57	286973
Rear	235	90	29	135264
Side	278	43	15	69556
Other	389	241	30	23687

Exhibit 93
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
PROPERTY DAMAGE ONLY - LIGHT TRUCKS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	0.17	0.07	0.02	99.74
Rear	0.17	0.07	0.02	99.74
Side	0.40	0.06	0.02	99.52
Other	1.60	0.99	0.12	97.29

Exhibit 94
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
PROPERTY DAMAGE ONLY - LIGHT TRUCKS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.16	0.17	0.19		0.06	0.07	0.08		0.01	0.02	0.02
Rear	0.15	0.17	0.20		0.05	0.07	0.08		0.01	0.02	0.03
Side	0.35	0.40	0.44		0.04	0.06	0.08		0.04	0.02	0.03
Other	1.44	1.60	1.76		0.87	0.99	1.11		0.08	0.12	0.17

All the Michigan truck data can be combined to obtain the results for all reported Michigan truck crashes with the same caveats that one has for cars.

Exhibit 95
MICHIGAN FREQUENCY POINT OF IMPACT
ALL REPORTED CRASHES - TRUCKS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	1188	349	123	329632
Rear	426	109	36	162904
Side	553	60	25	79824
Other	963	276	45	36746

Exhibit 96
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
ALL REPORTED CRASHES - TRUCKS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	0.36	0.11	0.04	99.50
Rear	0.28	0.07	0.02	99.63
Side	0.69	0.07	0.03	99.21
Other	2.53	0.73	0.12	96.62

Exhibit 97
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
ALL REPORTED CRASHES - TRUCKS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.34	0.36	0.38		0.09	0.11	0.12		0.03	0.04	0.04
Rear	0.25	0.28	0.30		0.06	0.07	0.08		0.02	0.02	0.03
Side	0.63	0.69	0.74		0.06	0.07	0.09		0.02	0.03	0.04
Other	2.37	2.53	2.69		0.64	0.73	0.81		0.08	0.12	0.15

The number of van fires in Michigan is small and many of the 95 PERCENT confidence intervals are so large that they include the estimates of other impact areas. This suggests that more data are needed to estimate the effects of impact area on fires in vans in the State of Michigan. These preliminary Michigan data are somewhat contrary to the findings of the FARS van data in section I of this study.

Exhibit 98
MICHIGAN FREQUENCY POINT OF IMPACT
INJURIES INCLUDING FATALITIES - VANS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	109	29	9	9565
Rear	88	4	4	4691
Side	47	4	4	2483
Other	68	9	5	1888

Exhibit 99
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
INJURIES INCLUDING FATALITIES - VANS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	1.12	0.30	0.09	98.49
Rear	1.84	0.08	0.08	97.99
Side	1.85	0.16	0.16	97.83
Other	3.45	0.46	0.25	95.84

Exhibit 100
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
INJURIES INCLUDING FATALITIES - VANS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.91	1.12	1.33		0.19	0.30	0.41		0.03	0.09	0.15
Rear	1.46	1.84	2.22		0.00	0.08	0.17		0.00	0.08	0.17
Side	1.33	1.85	2.38		0.00	0.16	0.31		0.00	0.16	0.31
Other	2.65	3.45	4.26		0.16	0.46	0.75		0.03	0.25	0.48

Exhibit 101
MICHIGAN FREQUENCY POINT OF IMPACT
PROPERTY DAMAGE ONLY - VANS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	116	53	16	61477
Rear	95	22	9	37495
Side	47	17	1	16707
Other	71	70	5	3979

Exhibit 102
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
PROPERTY DAMAGE ONLY - VANS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	0.19	0.06	0.03	99.70
Rear	0.25	0.06	0.02	99.67
Side	0.28	0.1	0.01	99.61
Other	1.72	1.7	0.12	96.46

Exhibit 103
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
PROPERTY DAMAGE ONLY - VANS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.15	0.19	0.22		0.06	0.09	0.11		0.01	0.03	0.04
Rear	0.2	0.25	0.30		0.03	0.06	0.08		0.01	0.02	0.04
Side	0.2	0.28	0.36		0.05	0.10	0.15		0.09	0.01	0.02
Other	1.32	1.72	2.12		1.30	1.70	2.09		0.02	0.12	0.23

As with cars and trucks the Michigan data for vans may be combined to provide information for all reported crashes. The results are:

Exhibit 104
MICHIGAN FREQUENCY POINT OF IMPACT
ALL REPORTED CRASHES - VANS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	225	82	25	41042
Rear	183	26	13	42186
Side	94	21	5	19190
Other	139	79	10	5867

Exhibit 105
MICHIGAN PERCENTAGE RATE POINT OF IMPACT
ALL REPORTED CRASHES - VANS

Impact Area	Leak Only	Fire Only	Leak & Fire	No Leak No Fire
Front	0.32	0.11	0.04	99.53
Rear	0.43	0.06	0.03	99.48
Side	0.49	0.11	0.03	99.38
Other	2.28	1.30	0.16	96.26

Exhibit 106
95 PERCENT CONFIDENCE LIMITS FOR PERCENTAGE RATE
by POINT OF IMPACT
ALL REPORTED CRASHES - VANS

Impact Area	Low Lim	% Leak	Up Lim		Low Lim	% Fire	Up Lim		Low Lim	Fire Leak	Up Lim
Front	0.27	0.32	0.36		0.09	0.11	0.14		0.02	0.04	0.05
Rear	0.37	0.43	0.49		0.04	0.06	0.08		0.01	0.04	0.05
Side	0.39	0.49	0.58		0.06	0.11	0.16		0.00	0.03	0.05
Other	1.91	2.28	2.66		1.01	1.30	1.58		0.06	0.16	0.27

An apparent contradiction seems to exist when the Michigan fire rates of cars with a rear impact area are compared to the similar results from the FARS analysis. To examine this issue further, the fatal crashes in Michigan were examined, by themselves, by impact area. As with the FARS data the rate of fire occurrence is about twice (8.59 percent [rear] vs. 4.98 percent [front]) the rate for a rear impact vs. a frontal impact (See Exhibit 30). However, like FARS there are many more fires with front impacts compared to rear impacts, in this case there are approximately six (6) times as many. Any apparent discrepancies between the Michigan data and the FARS data are most likely due to the shorter time period of the Michigan data 1982 to 1991 rather than 1979 to 1992 and or the single state of Michigan, with possibly different coding procedures, rather than the combined fifty states plus the District of Columbia. One would not expect the fire rates between Michigan and FARS to be the same. However, the rate of fire occurrence for both Michigan and FARS is considerably higher for rear impacts than for front impacts and both Michigan and FARS have more crashes with damage to the front than any other area.

There were a total of 6229 car crashes in Michigan of which 268 had a fire. This produces an average fire rate of 4.30 percent.

Exhibit 107
MICHIGAN FATAL FIRE Crashes in CARS by IMPACT AREA

Impact Area	Total Fatal Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	3151	157	4.22	4.98	5.74
Rear	291	25	5.37	8.59	11.81
Side	2124	69	2.49	3.25	4.00
Other	663	17	1.36	2.56	3.77

One can also examine the rate of fire by severity of the crash. Michigan partitions data by crashes that result in one or more fatalities, crashes that result in personal injury, but not a fatality and property damage only crashes. Exhibits 107 thru 115 contain this information for cars, trucks and vans. The front, rear, and side impact areas in general have the highest rates of fire occurrence for fatal crashes, lower rates for personal injury crashes that do not involve a fatality, and the lowest rate for crashes that only have property damage. Note that the Michigan data for fatal crashes involving trucks and vans often have five or less observations which experienced a fire. In such cases the estimates of the rates may be less stable than rates based on more observations.

Exhibit 108
MICHIGAN NON-FATAL PERSONAL INJURY FIRE Crashes in CARS
by IMPACT AREA

Impact Area	Total Injury Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	362604	1162	0.30	0.32	0.34
Rear	170888	236	0.12	0.14	0.16
Side	99270	173	0.15	0.17	0.20
Other	47071	192	0.35	0.41	0.47

Exhibit 109
MICHIGAN PROPERTY DAMAGE ONLY FIRE Crashes in CARS by IMPACT AREA

Impact Area	Total Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	1578187	1676	0.10	0.11	0.11
Rear	681155	620	0.08	0.09	0.10
Side	383934	327	0.08	0.09	0.09
Other	81307	1370	1.60	1.98	1.77

Exhibit 110
MICHIGAN FATAL FIRE Crashes in TRUCKS by IMPACT AREA

Impact Area	Total Fatal Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	750	1	0.88	8.95	11.29
Rear	28	1	0.88	3.57	10.45
Side	148	6	0.88	4.05	7.23
Other	266	4	0.04	1.50	2.97

Exhibit 111
MICHIGAN NON-FATAL PERSONAL INJURY FIRE Crashes in TRUCKS by IMPACT AREA

Impact Area	Total Injury Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	42314	174	0.35	0.41	0.47
Rear	17638	25	0.09	0.14	0.20
Side	10147	21	0.12	0.21	0.30
Other	12843	46	0.25	0.36	0.46

Exhibit 112
MICHIGAN PROPERTY DAMAGE ONLY FIRE Crashes in TRUCKS by IMPACT AREA

Impact Area	Total Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	287220	247	0.08	0.09	0.10
Rear	135383	119	0.07	0.09	0.10
Side	69614	58	0.06	0.08	0.10
Other	23958	271	1.00	1.13	1.27

Exhibit 113
MICHIGAN FATAL FIRE Crashes in VANS by IMPACT AREA

Impact Area	Total Fatal Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	91	3	0.00	3.30	6.97
Rear	9	2	0.00	22.22	49.38
Side	19	[illegible]	0.00	0.00	0.00
Other	36	1	0.00	2.78	8.15

Exhibit 114
MICHIGAN NON-FATAL PERSONAL INJURY FIRE Crashes in VANS
by IMPACT AREA

Impact Area	Total Injury Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	9621	35	0.24	0.36	0.48
Rear	4778	6	0.03	0.13	0.23
Side	2519	8	0.10	0.32	0.54
Other	1934	13	0.31	0.67	1.04

Exhibit 115
MICHIGAN PROPERTY DAMAGE ONLY FIRE Crashes in VANS by IMPACT AREA

Impact Area	Total Crashes	Number Fires	Lower 95% Limit	Percent Fire	Upper 95% Limit
Front	61662	69	0.09	0.11	0.14
Rear	37621	31	0.05	0.08	0.11
Side	16772	18	0.06	0.11	0.16
Other	4125	75	1.41	1.82	2.23

Michigan Vehicle Age

The number of vehicles involved in reported crashes partitioned by fuel leak only, fire only, fire and fuel leak, and neither fire nor fuel leak with the percentage of all crashes that had either a fire only or a fire and fuel leak, as well as, the percent of crashes that had a fire given that the crash had a fuel leak by the age of the vehicle in years appear in the Exhibits 116 and 117. Note that, as with the FARS data, for cars, the rate of occurrence of a fire increases as vehicles age. The Michigan rate of fire occurrence increases from 0.13 percent of all crashes in Michigan for new vehicles to 0.29 percent of all crashes for vehicles that are thirteen (13) years old. Note that the Y-axis scale for Exhibit 117 covers a narrower range [0 to 0.3 percent] than do the other exhibits - charts of this study [0 to 4.0 percent].

Exhibit 116
MICHIGAN - VEHICLE AGE in YEARS

Vehicle Age Years	Fuel Leak Only	Fire Only	Fire & Fuel Leak	No Fire No Leak	Percent Any Fire	Percent of Fire given Fuel Leak
0	1536	478	151	471729	0.13	9.0
1	1864	597	156	565839	0.14	7.7
2	1721	597	146	522219	0.14	7.8
4	1695	625	161	497600	0.16	6.7
4	1863	659	163	472457	0.17	8.0
5	1848	631	137	407813	0.19	8.0
6	1558	564	111	335916	0.26	6.7
7	1414	483	98	266217	0.22	6.5
8	1260	398	97	198318	0.25	7.1
9	1039	326	98	149184	0.29	8.5
10	848	239	57	108796	0.27	6.2
11	620	163	32	72732	0.26	4.9
12	364	97	20	42379	0.25	5.2
13	162	36	14	16801	0.29	8.0
Total	17792	5870	1439	4128000	0.18	7.5

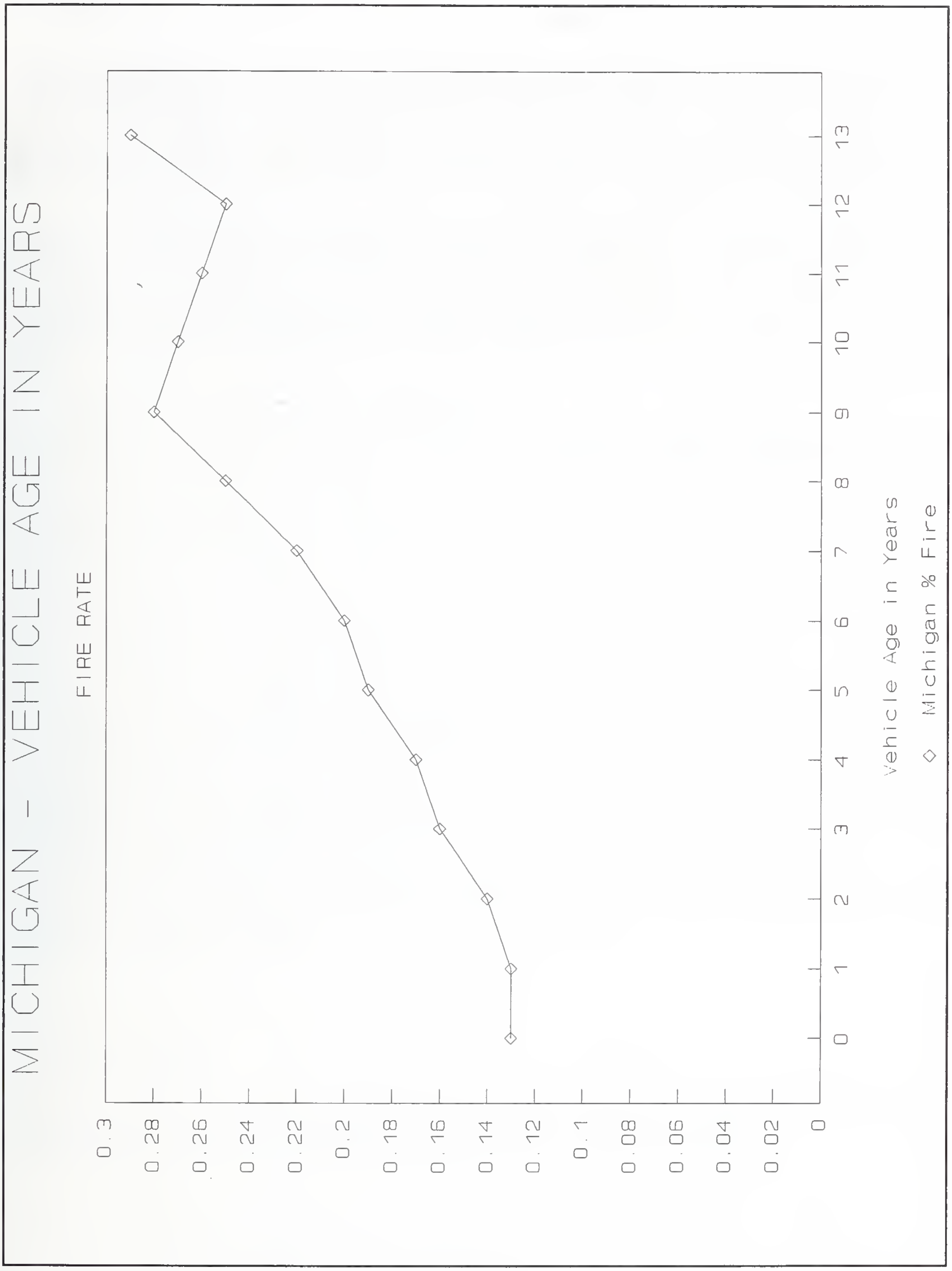

Exhibit 117
MICHIGAN FIRE RATE BY VEHICLE AGE

Probability of a Fire given a Fuel Leak

The row of total incidents, from Exhibit 108, provides the information to calculate an overall estimate of the Michigan conditional probability of a fire given a leak. One estimates this to be 1439/(1439 + 17792) = 0.075 or 7.5 percent. The probabilities of a fire given a leak were also calculated by age of the vehicle. The results suggest that fire rate given a fuel leak is somewhat stable, 7.5 percent ± 1.5 percent over the age range of vehicles examined.

The probability of a fire if no fuel leak was reported is calculated as 5870/(5870 + 4128000) = 0.142 percent. This may be combined with the data above to calculate the odds ratio of a fire given a fuel leak vs. a fire given that no fuel leak was reported, i.e. 7.5/0.142 = 52.8. That is a fire was 52.8 times as likely when a fuel leak was reported as opposed to when a fuel leak was not reported.

Note that there were (17792 + 1439 = 19231) fuel leaks, approximately 2.6 times the number of fires (5870 + 1439 = 7309).

NASS Data

The National Highway Traffic Safety Administration collects national traffic crash data to evaluate highway and vehicle safety standards. The National Accident Sampling System (NASS) Crashworthiness Data System (CDS) consists of twenty-four teams of crash researchers throughout the country. Each site samples the set of police accident reports involving passenger cars, light trucks and vans which were towed from the scene of the crash. The crashes investigated in CDS are a probability sample of all police reported crashes in the U.S. Each crash that occurs within a CDS team's area has a chance of being included in the sample. The chosen design makes it possible to compute national estimates. In particular, NASS estimates are available for burn injuries that were the result of a vehicle fire from 1988-1993. The burn injury data is obtained from detailed medical records of the injured occupants. The counts reported in this section are estimates of individuals who received an injury and in particular a burn injury.

Fires are rare events and occur in less than one percent of all crashes where a vehicle is towed from the scene of the crash. The total number of crashes sampled by the twenty four teams is relatively small, about 5000 per year. As a result, there are very few vehicles in the NASS database that had a fire, most likely less than 50 per year. The number of vehicles in the NASS database is so small that national estimates of burn injuries should be interpreted with care. Note, for example, in Exhibit 118 NASS estimates that no one year old vehicle had a fire that caused a burn injury. This does not mean that one year old vehicles do not have fires that cause burn injuries, but rather that there were no vehicles of this age that had a fire with burn injuries in the database. Although, due to the scarcity of the data, one cannot make precise estimates of burn injuries within vehicles that have a fire, the estimates can suggest relationships among the variables. For this reason the partitions of the data are rather coarse. This limitation of NASS data is for fires and other relatively rare events only and does not necessarily apply to other types of investigations. An underlying assumption of the burn injury data is that the burn resulted from a vehicle fire. As additional data are collected over the years and added to the database, this difficulty may be ameliorated. Confidence intervals and charts are not included for NASS estimates for this reason. The lower numbers in parenthesis are the unweighted number of observations on which the estimates are based.

NASS Vehicle Age

The data of Exhibit 118 does not suggest a relationship between vehicle age and occupants that had a burn injury and occupants that had any injury within vehicles.

Exhibit 118
OCCUPANTS WITH VEHICLE FIRE BURN INJURIES BY VEHICLE AGE

	Cars				LTV		
Vehicle Age	Burn Injuries	Total Injuries	Percent		Burn Injuries	Total Injuries	Percent
0	290 (4)	541383 (2536)	0.05		112 (4)	181280 (864)	0.06
1	0 (0)	701133 (3220)	0.06		0 (0)	219958 (1079)	0.00
2	370 (7)	746616 (3275)	0.05		66 (1)	223410 (1124)	0.03
3	43 (2)	782977 (3165)	0.01		79 (4)	239269 (1004)	0.04
4	1358 (4)	754250 (3201)	0.[illegible]		343 (4)	230655 (967)	0.15
5	361 (6)	720251 (2303)	0.05		64 (1)	153051 (687)	0.04
6	94 (3)	689186 (2302)	0.01		81 (3)	111630 (569)	0.07
7	127 (6)	519298 (2212)	0.02		0 (0)	96691 (395)	0.00
8	310 (7)	540005 (2078)	0.06		0 (0)	72822 (376)	0.00
9	428 (8)	535527 (1920)	0.08		191 (5)	65015 (279)	0.29
10	93 (3)	479164 (1836)	0.0[illegible]		15 (1)	54603 (227)	0.03
11	0 (0)	215999 (1304)	0.06		22 (1)	52303 (244)	0.04
12	95 (2)	221247 (936)	0.04		0 (0)	30049 (168)	0.00
13	75 (2)	114640 (652)	0.07		22 (1)	45082 (117)	0.0[illegible]
14	4 (1)	62737 (351)	0.01		17 (1)	27190 (97)	0.06

NASS Number of Vehicles Involved

Exhibit 119 shows a four-fold increase in rate of occupants with burn injuries for single-vehicle car crashes compared to multiple-vehicle crashes but the situation is reversed for light trucks and vans. This highlights an area for possible further investigation. Single-vehicle crashes of light trucks and vans are less than half as likely to have occupants with burn injuries as are multiple-vehicle crashes of light trucks and vans. Note however, that the number of light trucks and vans with fires in the NASS database, is very small. One may wish to compare the FARS data in Exhibits 21, 22, 23, and 24 with Exhibit 119. The FARS data show that single-vehicle fatal crashes are more likely to have a fire or a MHE fire than are vehicles in multiple-vehicle crashes.

Exhibit 119
OCCUPANTS WITH VEHICLE FIRE BURN INJURIES BY Crash COMPLEXITY
Single-vehicle VS Multiple-vehicle Crashes

	Cars				LTV		
Crash Complexity	Burn Injuries	Total Injuries	Percent		Burn Injuries	Total Injuries	Percent
Single	2104 (29)	1798839 (8267)	0.12		444 (15)	695203 (2969)	0.06
Multiple	1548 (26)	5944160 (23331)	0.03		598 (13)	1115418 (5265)	0.05

NASS Damaged Area

NASS estimates that of the 617335 car occupants with injuries that occurred in rollover crashes, 1020 were attributed to occupants with burn injuries caused by vehicle fires. Rollovers have the highest rate of occupants with burn injuries, 0.16 percent for cars and a somewhat lower rate 0.08 percent for light trucks and vans. The results are in Exhibit 120. Note that there are over twice as many occupants with burn injuries where the front of a car was damaged as opposed to the rear (864 vs. 383). However, the rate of occupants with burn injuries is twice as high for damage to the rear compared to damage to the front. See Exhibit 30 for comparison to the FARS data. One notes that the rate of occupants with burn injuries for cars are the highest for rollover and damage to the rear. The corresponding FARS data appear in Exhibits 36 and 38.

Exhibit 120
OCCUPANTS WITH VEHICLE FIRE BURN INJURIES BY DAMAGED AREA

	Cars				LTV		
Damaged Area	Burn Injuries	Total Injuries	Percent		Burn Injuries	Total Injuries	Percent
Rollover	1020 (14)	617335 (2934)	0.16		357 (10)	464007 (2254)	0.08
Front	864 (13)	3121016 (13251)	0.03		475 (9)	646389 (3195)	0.07
Rear	383 (12)	660560 (1740)	0.06		0 (0)	76710 (240)	0.00
Side	893 (12)	1757839 (7133)	0.05		136 (6)	218832 (948)	0.06
Other	490 (12)	1586249 (6540)	0.03		75 (3)	404678 (1597)	0.02

NASS Object Struck

Cars striking narrow objects, such as utility poles, have the highest rate of burn injuries. This is consistent with the FARS data in Exhibit 40.

Exhibit 121
OCCUPANTS WITH VEHICLE FIRE BURN INJURIES BY OBJECT STRUCK

	Cars				LTV		
Object Struck	Burn Injuries	Total Injuries	Percent		Burn Injuries	Total Injuries	Percent
Vehicle	1312 (23)	5072247 (19445)	0.03		598 (13)	911980 (4268)	0.07
Narrow	1180 (14)	681042 (3390)	0.17		196 (7)	162940 (808)	0.12
Fixed	499 (10)	429128 (2027)	0.12		44 (2)	156176 (579)	0.03
Other	0 (0)	56692 (195)	0.00		22 (1)	18734 (83)	0.12
Overturn	650 (7)	400301 (1678)	0.16		182 (5)	299762 (1249)	0.06

NASS Delta V

Delta V is often not available for NASS cases, either because some crash types (such as rollovers) are not applicable for a delta V computation, or because some vehicles cannot be located to determine the crush measurements and associated characteristics. In general, one would expect that as delta V increases, the rate of occupants with burn injuries would also increase. As additional data becomes available, this pattern may emerge. The best available estimates based on the data to date appear in Exhibit 122.

Exhibit 122
OCCUPANTS WITH VEHICLE FIRE BURN INJURIES BY DELTA V

	Cars				LTV		
Delta V	Burn Injuries	Total Injuries	Percent		Burn Injuries	Total Injuries	Percent
00-10	0 (0)	626962 (1668)	0.00		0 (0)	99888 (400)	0.00
11-20	16 (1)	1895883 (7312)	0.00		17 (1)	338271 (1508)	0.01
21-30	89 (3)	552587 (3478)	0.02		0 (0)	101419 (712)	0.00
31-40	60 (4)	115386 (1114)	0.05		15 (1)	15300 (210)	0.10
41-50	216 (7)	25006 (343)	0.86		10 (1)	6151 (81)	0.16
Over 50	89 (3)	9602 (199)	0.92		94 (3)	1595 (30)	5.89

NASS A.I.S. Severity

The maximum A.I.S/ injury severity data is available in the NASS data files. Exhibit 123 has a different structure than the previous exhibits. The second and sixth columns headed Burn Injuries contain the number of individuals who received an A.I.S. burn injury of the listed severity. If an individual received more than one burn injury, the individual is listed under the highest burn injury severity received. Columns three and seven headed Maximum Injury contain the subset of the individuals that received a burn injury, but did not receive an injury that resulted in a more severe A.I.S. code. For example, of the 896 individuals within cars that suffered a minor burn injury due to a vehicle fire, 35 individuals or 3.91 percent did not receive any injury with a more severe A.I.S. severity level.

Exhibit 123
OCCUPANTS WITH VEHICLE FIRE BURN INJURIES
BY MAXIMUM BURN INJURY A.I.S.

	Cars				LTV		
A.I.S. Severity	Burn Injuries	Maximum Injury	Percent Maximum		Burn Injuries	Maximum Injury	Percent Maximum
Minor	896 (4)	35 (1)	3.91		281 (8)	141 (3)	50.18
Moderate	216 (3)	0 (0)	0.00		0 (0)	0 (0)	N/A
Serious	63 (1)	63 (1)	100.00		107 (4)	93 (3)	86.92
Severe	0 (0)	0 (0)	N/A		0 (0)	0 (0)	N/A
Critical	409 (7)	409 (7)	100.00		36 (2)	36 (2)	100.00
Maximum	1954 (37)	1954 (37)	100.00		618 (14)	618 (14)	100.00
Unknown	114 (3)	74 (2)	94.91		0 (0)	0 (0)	N/A

NASS Entrapment

Entrapment has a fundamentally different type of relationship with fire than do the previous NASS variables which have been examined so far. The previous variables are expected to have a "causal" relation with fire. That is a change in the crash complexity or Delta V is expected to change the rate of vehicle fires. However, although entrapment like extrication, see Exhibit 73, does not cause fires and fires do not cause entrapment, the two variables may be associated.

To examine entrapment the NASS partition of minor and major fire are used. NASS classifies a fire as a major fire if the fire involved the whole passenger compartment or several different compartments such as the engine compartment, trunk compartment or undercarriage.

The rate of individuals that are entrapped in major fires is 1.95 percent, the lowest of the three groups. The rate of entrapment for minor fires, 21.35 percent, is almost eleven times greater than the rate for major fires. The results are found in Exhibit 124.

Exhibit 124
ENTRAPMENT

Fire Level	Entrapped	Not Entrapped	Percent Entrapped
No Fire	24465 (355)	3973770 (16045)	6.12
Minor Fire	1222 (6)	4502 (41)	21.35
Major Fire	131 (4)	6599 (90)	1.95

S. C. Partyka, in her July 1992 paper "Fires and Burns in Towed Light Passenger Vehicle Crashes" Office of Vehicle Safety Standards points out that NASS also provides information on the lack of operable doors near the occupant's seat position which can also contribute to burn injuries. Interested readers are referred to her paper.

NASS Fire Origin

The origin of the fire is partitioned into three levels; fuel system, engine compartment and other. In this context, the fuel system consists of the fuel tank(s), fuel supply and vent lines and the filler neck. The engine area denotes the open or closed area which houses the engine. For an engine area fire, the cause for the fire is inconsequential, it may be electrical or fuel related. The fire's relative location to the engine is the important consideration. Note that virtually all of the fuel system fires, 1908 out of 1927 or 99.01 percent, are major fires. If the origin of the fire is not the fuel system, then less than half of the fires are major fires. The results are in Exhibit 125.

Exhibit 125
ORIGIN of FIRES

Fire Level	Fuel System	Percent Fuel System	Engine Area	Percent Engine Area	Other	Percent Other
Minor	19 (2)	0.33	4613 (36)	80.59	1092 (9)	19.07
Major	1908 (25)	28.35	4342 (60)	64.53	479 (9)	7.12

Conclusions and Recommendations

The rate of postcollision fires in fatal 1978 or newer car crashes for the United States from 1979 to 1992 averages 2.42 percent (Exhibit 21). The rate of postcollision fires in fatal 1978 or newer car crashes in Michigan from 1982 to 1991 averages 4.30 percent (Exhibit 107). The rate of postcollision fires in all 1978 or newer car crashes in Michigan from 1982 to 1991 averages 0.18 percent (Exhibit 86).

Based on data from the Fatal Accident Reporting System (FARS) it is estimated that 2700 deaths were due to a fire in a 1978 or newer car truck or van. If all deaths, in vehicles coded as most harmful event fire are included the total rises to 3557. The maximum number of possible deaths due to fire is calculated to be 4973. On an annual basis, over the last three years, this is approximately 261, 340, and 490 deaths due to fire per year depending on the measure used (Exhibit 71). Under similar conditions, NASS estimates that there are approximately 670 burn injuries per year. Since 1979 there has been a slight decline in the percent of deaths due to fire compared to the total number of deaths in 1978 or newer model cars, trucks and vans (Exhibit 72).

The vehicle age of cars has a statistically significant effect on fire. The results show that as cars age they are more likely to have a fire (Exhibits 15 and 117).

The rate of fire and MHE fire for rollover and cars with damage to the rear shows substantial variation by weight class. Rollovers, of weight class 5, have the highest rate for fire 5.33 percent and MHE fire 2.08 percent. Cars with damage to the rear of weight class 4 have the highest rate of fire 6.16 percent and MHE fire 2.62 percent (Exhibits 33 and 35).

Light trucks are more susceptible to fires than are cars or vans. However, there are approximately 3 times as many fires in cars as in light trucks. Over the period of the study, 1979 through 1992, 6854/2054 cars, 2280/775 light trucks and 356/106 vans had fires/MHE fires. The increasing popularity of the passenger minivan during the study period is expected to continue. This may lead to increasing incidents of fires within the van category (Exhibits 12, 23, and 25).

Higher posted speed limits are associated with increased rates of fire/MHE fire. An increase in the posted speed limit of ten mph raises the incidence of fire/MHE fire by 41.1 percent and 50.9 percent, respectively. Raising the speed limit from 30 mph to 55 mph (an increase of 25 mph) raises the likelihood of a fire/MHE fire in a fatal crash by 136.3 percent (more than double) and 179.7 percent (more than double), respectively (Exhibit 74). An increase in the speed limit from 30 mph to 65 mph raises the likelihood of a fire/MHE fire, in a fatal crash, by 233.4 percent (more than triple) and 322.1 percent (more than quadruple). While posted speed limit does not necessarily indicate actual travel speeds, it is nonetheless a surrogate measure of travel speed, and an important predictor of the likelihood of postcollision fire.

The area of damage, i.e., the principal area where the vehicle was struck, has a statistically significant effect on the rate of fire/MHE fire. Cars are more suspectable to this factor than are light trucks and vans, presumably due to the location of the fuel tank, generally in the rear. If a car involved in a fatal crash is struck in the rear, it is approximately 140 percent and 340 percent more likely to have a fire/MHE fire, respectively, than a car with damage

to the front (Exhibit 75 and 77). Over the time period of the study, 1979 through 1992, there were 3275/839 cases of fatal crashes where a car was struck in the front and had a fire/MHE fire. During this period there were 640/270 cases where a car was struck in the rear and had a fire/MHE fire (Exhibit 30). The data suggest that crash tests of cars should include frontal crash tests to address the largest number of postcollision fires, and rear crashes, to address the greatest likelihood of postcollision fires, as part of the testing procedure.

The object that is struck by a vehicle involved in a fatal crash affects the likelihood of a fire/MHE fire. Vehicles striking narrow objects, such as telephone poles, are more likely to have a fire/MHE fire than vehicles striking other types of objects. In particular, a vehicle striking a narrow object is 27.6 percent and 23.7 percent more likely to have a fire/MHE fire, respectively, than vehicles that strike other fixed objects (Exhibit 74). However, there are relatively few cases of a vehicle being struck in the rear by a narrow object, (see Exhibits 46-51), i.e., both types of events occur, but usually not together.

The Michigan data show that car crashes involving injuries have a significantly higher rate of fire than do crashes that only have property damage if the damage is to the front rear or side. However, the situation is reversed for the "other" impact areas, which includes damage to the under carriage (Exhibits 81 and 84).

Light truck in crashes with personal injury have a higher rate of fire with front impacts than with side impacts (Exhibit 90).

The Michigan data was used to calculate the conditional probability of a fire given a fuel leak to be 0.075 or 7.5 percent. However, fire was 52.8 times as likely if a fuel leak was reported as opposed to when a fuel leak was not reported (Exhibit 116).

Most burn injuries, due to vehicle fires, occur in crashes with Delta V in excess of 20 mph (Exhibit 122).

Virtually all fires that originate in the fuel system, rather than the engine compartment, are major fires. If the origin of the fire is not the fuel system, this usually means the fire originated in the engine compartment, then less than half of the fires are classified as major fires (Exhibit 125).

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